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China's Race to Innovate in Critical Technologies: What Can Europe Learn?

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Abstract

This policy brief examines China's rapid ascent in frontier innovation across artificial intelligence (AI), semiconductors, and quantum computing, drawing on our recent analysis of patent breakthroughs in these critical technologies in China, the European Union (EU) and the United States (US). The findings reveal a competitive landscape where the US maintains overall leadership, China excels in targeted subfields with remarkable speed, and the EU lags significantly in patent breakthroughs and knowledge diffusion. China's strengths stem from a hybrid innovation ecosystem blending public and private actors, enabling quick replication of global novelties despite external restrictions. In contrast, Europe's fragmented markets and reliance on public research hinder scale and commercialization. To bridge this gap, Europe must not only increase research and development in critical technologies but also further integrate its national innovation ecosystems .

In this policy brief, we review how China fares, compared to the US and the EU, in terms of breakthroughs in critical technologies, how fast the replication of such breakthroughs is across geographies and who are the main actors behind this innovation. Our findings, based on recent research by Garcia Herrero et al. (2025) confirm that the US still dominates in AI and, especially quantum, while China is moving fast in all, especially in semiconductors where the US dominance is waning.

· China ranks second although it already excels in some subfields of AI, surveillance and arial driving, but also on semiconductor fabrication. For quantum, while the gap is still arge with the US and even, to a lesser extent, with the EU, China is making great strides in some subfields like quantum sensors.

· The EU trails with fewer breakthroughs in general but, most importantly, it is much slower than China or the US in the replication of radical novelties in any of the three fields. Instead, the EU's novel patents appear to be quickly replicated by both the US and China.

· China's success stems from cross-sector dynamism and efficient resource channelling via Five-Year Plans, not just subsidies. The US, instead, benefits from a very large ecosystem of science and innovation as ell as venture capital at a huge scale. The EU is hampered by bureaucratic barriers, weak private involvement but also the lack of a EU-level innovation market.

· Based on our findings, we would recommend the EU to redesign institutions for a faster replication of key breakthroughs in critical technologies. Furthermore, sandboxes for faster patenting would be welcome as well as the refocus of EU's largest innovation financial effort, namely Horizon Europe. In the same vein, given the fragmentation of the European innovation market, establishing a Critical Tech Observatory for real-time monitoring of innovation would be very welcome. Finally, integrate military demand to boost scale and speed in dual technologies – most of which critical ones -seems warranted.

Contents

1. Introduction

In an era defined by geopolitical tensions and technological rivalry, the race for supremacy in critical technologies such as artificial intelligence (AI), semiconductors, and quantum computing has become a cornerstone of economic and strategic power. The stakes are high: these technologies underpin everything from autonomous weapons to climate modelling, and control over them shapes global supply chains, national security, and economic resilience

There is a general view that China's ascent in these domains is so quick that it might possibly have already caught up with the US, guaranteeing the self-reliance that China has been longing for for decades. Another important question for the European Union is how far behind it is in this technologies and whether spillovers are strong enough to mitigate the problems of not having enough indigenous breakthroughs in these critical technologies

This policy brief delves into China's performance relative to the US and EU, when it comes to breakthroughs in critical technologies but also the speed at which different countries manage to replicate breakthroughs from others. Finally, we also look into the actors (companies or research institutions) which create the bulk of these breakthroughs and how they may differ across geographies.

To that end, we draw on two empirical analysis by by García Herrero, Krystjanczuk and Schindowski (2025a and 2025b)1 and assess how China has perfomed relative to the US and the EU in innovating in critical technologies. We conclude that China has positioned itself as a swift second to the US, often outpacing the EU in the number of radical technologies (i.e. number of patents with key breakthroughs for each fo these three critical technologies). Secondly, we look into the speed at which such technological breakthroughs move from one country to another. China and the US. excel in terms of the speed of adoption of others' radical novelties, while the EU lags behind.

These results are important for a number of reasons. Being able to be at the frontier of innovation in critical technologies if crucial in the current race for hegemony between the US and China. This is all the more so since both countries are increasingly using economic security to keep such innovation with borders or at least not reaching the other contender. This is why the second part of our analysis, namely the speed at which new breakthroughs in these technologies can be replicated by another country, is also crucial. The fact that Europe lags is both realms (generation of breakthroughs and adoption) is alarming and deserves further attention.

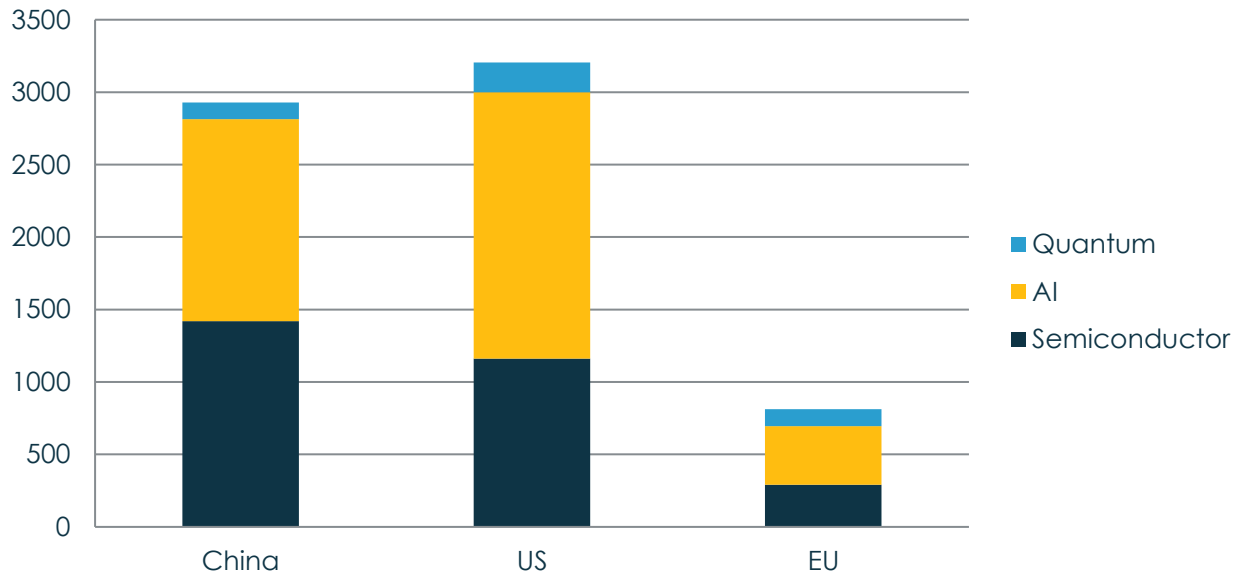
The rest of the policy brief is structured as follows. In section 2, we review where China stands in terms of breakthroughs, compared to the US and the EU. In section 3, we look in the main actors behind this innovation. In section 4, we look into the speed of adoption of other countries' breakthroughs. Section 5 draw relevant conclusions for Europe.

2. Where does China stand ?

Since 2019, China has seen a massive increase in patent filings in the three fields but not yet outstripping the US in relevance of such patents (Graph 1). When focusing on key patents (so-called "radical novelties" based on our research), China comes second for AI and semiconductors, after the US. The UE follows China at a far distance except for quantum

technologies where both the EU and China seem to be at par in terms of radical novelties, although still very much behind the US.

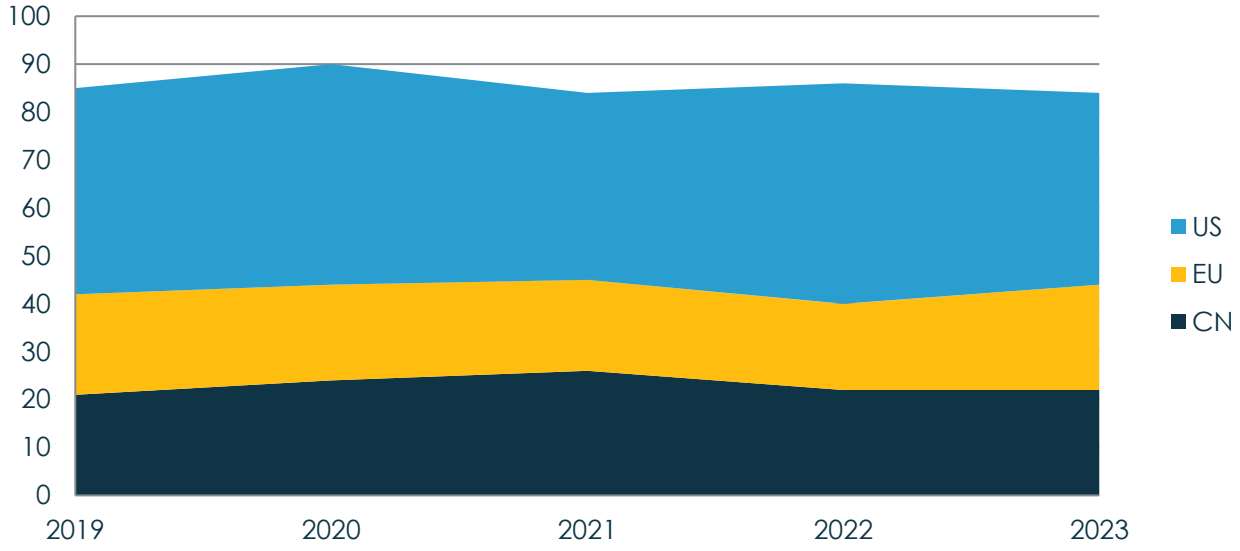
Figure 1: Radical novelties by company headquarter (2019-2023)



Source: García-Herrero, A., Krystyanczuk, M., & Schindowski, R. (2025). "Radical novelties in critical technologies and spillovers: How do China, the US and the EU fare?"

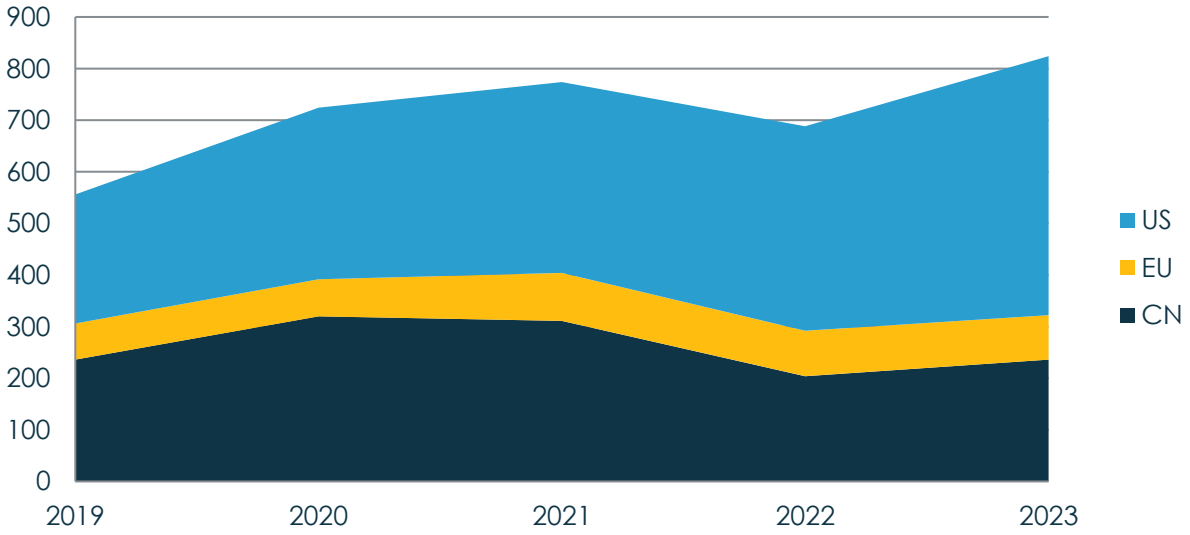
China's excellence is particularly evident in applied and scale-oriented subfields, where its innovations address real-world deployment challenges at massive volumes. In AI, China dominates in computer vision for surveillance and autonomous systems—generating over 40% of global novelties in facial recognition algorithms as seen in integrations for smart city infrastructure that process millions of data points daily. In drone and aerial vehicle AI, Chinese firms lead with 55% of the total number of radical novelties. This includes pioneering swarm intelligence for logistics, far surpassing the US, let alone the EU. For semiconductors, China's prowess shines in fabrication and materials processing, where it holds 65% of novelties in advanced packaging techniques like 3D stacking for high-density memory, critical for edge AI devices. It should be noted that Taiwan and South Korea and not included in our analysis where the number of patents is probably very large as well. In quantum computing, while not dominant, China excels in trapped-ion systems for scalable sensors that enhance precision measurement for industrial applications like earthquake prediction.

Figure 2. Evolution of radical novelties in quantum computing (2019-2023)



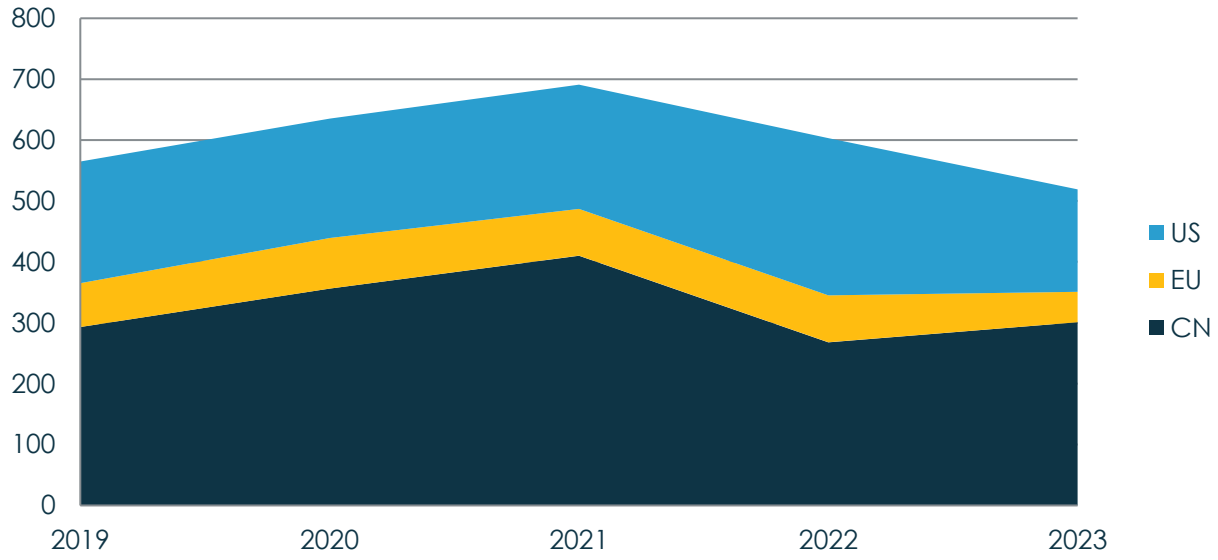
Source: García-Herrero, A., Krystyanczuk, M., & Schindowski, R. (2025). "Radical novelties in critical technologies and spillovers: How do China, the US and the EU fare?"

Figure 3. Evolution of radical novelties in AI (2019-2023



Source: García-Herrero, A., Krystyanczuk, M., & Schindowski, R. (2025). "Radical novelties in critical technologies and spillovers: How do China, the US and the EU fare?"

Figure 4: Evolution of radical novelties in semiconductors (2019-2023)



Source: García-Herrero, A., Krystyanczuk, M., & Schindowski, R. (2025). "Radical novelties in critical technologies and spillovers: How do China, the US and the EU fare?"

The EU's opportunities for catch-up emerge in complementary niches that could synergize with broader efforts. In quantum photonics—a subfield where the EU claims 28% of novelties while China stands at 25%—Europe's strengths are in fiber-optic entanglement for secure networks. In AI ethics and explainable models, the EU trails minimally at 18% versus China's 20%, with novelties in bias-mitigation frameworks that align with General Data Protection Regulation (GDPR), offering a pathway to exportable standards. For semiconductors, Europe's 15% share in lithography might not be showing Europe's clear advantage, bolstered by ASML's near-monopoly on extreme ultra-violet (EUV) tools.

3. Actors Driving Innovation: China vs. US and Europe

When looking at the actors behind the game changing patents analysed in the previous section, we find that they are quite different in the three economic regions[2]. In other words, innovation ecosystems vary sharply with Chinese innovators being much more diverse than US ones while Europe lies in between although it relies more on public research centres.

Starting with the US, private tech companies dominate the whole spectrum of key novelties. Microsoft, IBM, Intel, and Qualcomm stand out for appearing across multiple critical technologies while Micron, Google and Amazon also feature in more than one area (i.e., being among the top 10 innovators in the US by number of novel patents). Other tech companies such as Micron, Google, and Amazon, are also among the top innovators across multiple critical technologies. This high concentration in tech is a risk but also offers the advantage of fostering synergies. Furthermore, this concentrated ecosystem, backed by the largest venture

capital market in the world by far, ensures rapid commercialization although it runs the risk of siloing innovation into the digital realm rather than diversified across physical industries.

Table 1. US top 10 patentees in critical technologies

Artificial Intelligence	Semiconductors	Quantum Computing
Qualcomm	Onsemi	Zapata Computing
Oracle	Texas Instruments	University of Maryland
Nvidia	Qualcomm	Rigetti
Microsoft	Microsoft	Red Hat
Micron	Micron	Microsoft
Intel	Lumileds	IonQ
IBM	Intel	Intel
Google	IBM	IBM
Amazon	Applied Materials	Google
Adobe	Apple	Amazon

Source: García-Herrero, A., Krystyanczuk, M., & Schindowski, R. (2025). "Which companies are ahead in frontier innovation on critical technologies? Comparing China, the European Union and the United States."

China's landscape features a balanced mix of private and public entities, but its true differentiator is the involvement of very different companies from varied sectors, making the ecosystem more innovative through unexpected synergies. National champions in semiconductors (TCL Technology at 74.8% in 2019, Changxin Memory, Yangtze Memory, but also SMIC) coexist with telecom giants (Huawei at a whooping 34.1% of total AI chips), but breakthroughs also come from insurance firms like Ping An, which leads in AI novelties for predictive health analytics (25% share in medical imaging), adapting models from finance to biotech for nationwide telemedicine. Tech platforms like Tencent and ByteDance innovate in video processing AI (40% novelty share), but so do robotics players like Autel and UBTECH, pioneering quantum-enhanced sensors for industrial automation, and even consumer goods firms like Haier, contributing in efficient cooling for data centers. This diversity—spanning 15+ sectors with tight industry-academia ties like Tsinghua University's hubs—enables diffusion into products like surveillance AI or e-commerce logistics. China's model incentivizes any firm with high R&D intensity, via industrial policy programs like "Little Giants" (for a review of the effectiveness of the Little Giants program see García Herrero and Krystyanczuk 2024[3]).

Table 2. China top 10 patentees in critical technologies

Artificial Intelligence	**Semiconductors**	**Quantum Computing**
UBTECH Robotics	Yangtze Memory	Tencent
Tencent	TCL Technology	TCL Technology
Ping An	SMIC	South China Normal University
Oppo	Ningbo Semiconductor	Shenzhen Polytechnic
Huawei	InnoScience	Shenzhen Jingtai Technology
CloudMinds Robotics	Huawei	QuantumCTek
ByteDance	Enkris Semiconductor	Origin Quantum
Baidu	Changxin Memory	Huawei
BOE Technology Group	BOE Optoelectronics	Hengtong Qasky Quantum
Autel Robotics	AAC Acoustic	China Electronics Technology Group

Source: García-Herrero, A., Krystyanczuk, M., & Schindowski, R. (2025). "Which companies are ahead in frontier innovation on critical technologies? Comparing China, the European Union and the United States."

Europe relies heavily on public research centers, particularly in quantum where institutions like CEA (France) and universities (RWTH Aachen, Valencia, Delft) lead novelties, generating 60% of EU output but struggling with commercialization. Private company involvement is limited, especially in AI and semiconductors but with notable exceptions like Ericsson and Nokia in AI for 5G edge computing and Infineon at 42.86% of total novelties in semis for power devices. By making it harder to recoup fixed innovation costs, the fragmentation of the single market may contribute to the fact that compared to the US and China, far fewer European actors innovate across several critical technologies (only Ericsson and CEA rank across all three). This hampers Europe's ability to translate research into market dominance and contrasts sharply with China's inclusive diversity, where even non-tech firms drive 40% of novelties.

Table 3. EU top 10 patentees in critical technologies

Artificial Intelligence	**Semiconductors**	**Quantum Computing**
Stanley Robotics	Siemens	equal1.labs
Siemens	STMicroelectronics	RWTH Aachen

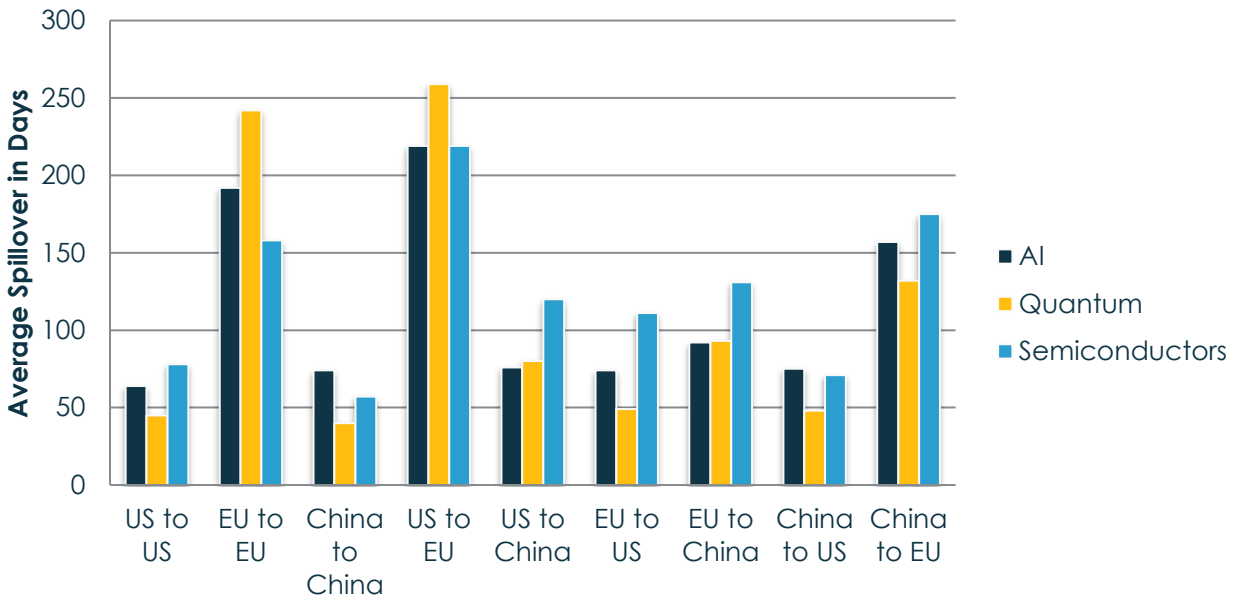
Safran	Robert Bosch	Polytechnic University of Valencia
SAP	Osram Opto Semiconductors	IQM Finland
Robert Bosch	Nexperia	Ericsson
Nokia	Infineon	Delft University of Technology
Ericsson	Ericsson	Compsecur
Carl Zeiss	CEA	CEA
CEA	Aledia	Bull
Accenture	ASM IP Holding	Buendia Jose

Source: García-Herrero, A., Krystyanczuk, M., & Schindowski, R. (2025). "Which companies are ahead in frontier innovation on critical technologies? Comparing China, the European Union and the United States."

4. Speed of Knowledge Spillovers: Quick for China and the US and Slow in Europe

While competition for top positions in novel patents is important, so is the ability to replicate great innovative ideas. To assess how China, the EU and the US are doing in replicating breakthroughs in innovation in critical technologies, a spillover analysis was conducted, yielding really sombre results for Europe. Spillovers refer to the spread of new technologies or ideas from one region to others. They are calculated by measuring the time lag between the publication of an original, radically novel patent and the appearance of similar technologies in patents from other regions. Among the three critical technologies analysed, AI spreads the fastest but China excels replicating novel patents originated in the US or the EU in only in six months. Bidirectional US-China flows (e.g., Nvidia designs inspiring Huawei alternatives) are quite obvious as the US also replicates Chinese patents fast, and so those from the EU. EU member states replicate novelties from China or the US at a much slower pace, namely 18-24 months. This is also true for novelties within the EU (e.g., German to French or the other way around), exacerbated by the dependence on public research centres which limits the role of the private sector in accelerating technological diffusion. One can think of meany reasons for this worrisome outcome, such as language divides, a weak venture ecosystems and, possibly excessively data protection (GDPR).

Figure 5. Cross-regional spillovers per field by direction (in average number of days)



Source: García-Herrero, A., Krystyanczuk, M., & Schindowski, R. (2025). "Radical novelties in critical technologies and spillovers: How do China, the US and the EU fare"

5. Implications

The comparative analysis of innovation in critical technologies reveals a stark divergence in trajectories among the US, China, and the EU. The US continues to lead in the production of radical novelties across AI, semiconductors, and quantum computing, bolstered by a concentrated ecosystem of private tech giants that excel in high-value subfields and foster rapid commercialization. From Google's multimodal AI to IBM's quantum supremacy claims, the US's model leverages market forces to sustain a 35-40% global share of radical innovations, turning theoretical breakthroughs into trillion-dollar industries.

China, while trailing the US overall, has emerged as a formidable second-place contender, particularly dominating in semiconductor fabrication and selected AI applications like surveillance vision and aerial swarms thanks to its hybrid model of diverse sectoral actors and state-supported scale that allows for quick absorption and adaptation of global breakthroughs. In contrast, the European Union, despite pockets of strength in quantum photonics and explainable AI, consistently underperforms, generating far fewer novelties and struggling with sluggish spillovers that hinder its ability to keep pace. Europe's 10-15% shares reflect excellence in niches—like ASML's EUV monopoly - but fragmentation of innovation is a clear hurdle. This disparity is not merely quantitative but structural: China's outperformance over Europe arises from its massive investments—such as $90 billion in semiconductor subsidies—coupled with a unified market that enables half-year replication times, diverse actors spanning telecom, insurance, and tech for broad diffusion and strong industry-academia linkages that turn research into deployable products.

Europe's challenges, rooted in market fragmentation, regulatory hurdles, language barriers, and an overreliance on non-commercial entities, result in lagging innovation in critical technologies but also in adoption and insufficient private-sector scaling.

While industrial policy is an important factor behind's China innovation drive, a simplistic judgement attributing China's success mainly to large subsidies should be avoided. China's industrial policy strategically aligns long-term objectives outlined in Five-Year Plans—such as those in "Made in China 2025"—with flexible implementation mechanisms, including the selection of specialized firms through programs like the "10,000 Little Giants," which prioritize R&D intensity and sectoral concentration to channel resources efficiently into different technologies, including the critical ones analysed in this paper. The policy levers go beyond subsidies to other incentives like tax breaks for research and development expenditure, underscore China's ability to drive outperformance in targeted domains.

While the EU should not seek to copy China's industrial policy, given the marked institutional differences, it should realize that putting innovation at the centre is certainly a good idea, More generally, these dynamics underscore a critical lesson for Europe: in a world where scale and speed define technological leadership, fragmented excellence risks obsolescence. The US's private vigour and China's state-orchestrated agility—fuelled by diverse innovators—contrast Europe's regulatory caution, which, without reform, will continue to cede ground to the US and China. By learning from China's ascent—adapting its subsidy precision, spillover efficiency, and cross-sector dynamism—the EU can reorient its innovation policies. The EU also needs to focus, much more than the US and China, on the scale of its market, not only for goods and services but also for innovation.

6. Policy Recommendations

To emulate China's strengths and address its own structural weaknesses, Europe should implement a multifaceted strategy cantered on enhancing basic research but also accelerating diffusion, enhancing scale by integrating the single market but also and strengthening commercialization linkages. This requires not just funding but institutional redesign, drawing selectively from China's industrial playbook, especially on the innovation focus, while preserving EU values like openness and sustainability. Some more specific recommendations for the EU are the following.

First, EU-wide sandboxes should be established for patent licensing and technology transfer. Such dedicated regulatory environments would support cross-border research collaborations and reduce the bureaucratic barriers that currently double Europe's replication times compared to China's agile adaptations.

Second, Horizon Europe funding might need to be further focused toward critical technologies, especially on deployment incorporating direct monetary incentives for private firms to prototype and marketize novelties, much like China's state-backed subsidies that have propelled its semiconductor ecosystem forward.

Third, leveraging public procurement as a demand-generation tool is essential. By mandating the incorporation of critical technologies in EU-wide public contracts—from AI in public services

to quantum-secure communications in infrastructure—Europe can create immediate markets that pull innovations from labs to deployment, fostering the virtuous cycle of product diffusion and reinvestment that sustains China's current edge over the EU. In that regard, expanding the EU's €2 trillion public procurement market via a "Critical Tech Mandate," requiring 30% of tenders (e.g., defense, transport) to feature EU-sourced AI/semiconductors by 2028, with penalties for non-compliance could be the way to go, given how much China has pushed its own indigenous innovation to catch up with the US.

Fourth, a Critical Tech Observatory at the EU level should be created, possibly under the European Commission, to provide real-time monitoring of global patent landscapes, enabling proactive "fast-follower" strategies that identify and replicate high-potential novelties. While this may look like China's Ministry of Industrial an Information Technology (MITT), the EU should follow a much more open and collaborative approach, especially with like-minded partners. Finally, Europe's push for a larger – but also more integrated - military expenditures should create the demand for such dual technologies in the dual-use space.

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