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Open code, closed system: the role of open source in China's technological rivalry with the United States

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China is striving to build its own technological ecosystem – one that is not only independent, but also resilient to sanctions and restrictions imposed by the United States, currently the most prolific user of such measures. As a result, the race for supremacy in this area has become a key element of the broader US–China rivalry. Technological superiority enables a country to impose technical, legal, economic, and even social standards, influence the adoption of new solutions by other states and preserve its economic dominance. Due to the two countries' differing roles in the existing global division of labour and the pre-eminence of American companies and research centres, China now faces the imperative of narrowing its technological gap with the United States. Achieving this requires immense organisational, human, and capital effort. Against this backdrop, Beijing has opted for a development model based on open-source solutions, which helps to spread the costs and risks of investing in new technologies while enabling faster and broader implementation. It also opens opportunities to tap into talent from outside China and facilitates technological expansion abroad.

At the same time, China's use of open-source is part of a broader effort to enhance security by gradually eliminating foreign source code over which Chinese users have no control. Open-hardware architecture simultaneously broadens the scope for developing domestic semiconductors and industrial robots using technology resistant to Western sanctions. As a result, China's approach to open-source not only influences the direction of global technological transformation, but also serves as a source of inspiration for some countries, while prompting others to adapt their development strategies.

Open-software and open-hardware

Today, virtually every element of the technologies we interact with on a daily basis – whether the Internet, smartphones, cars, or household appliances – is at least partially built upon and operates

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using open-source code,[1] or open-hardware architecture.[2] Linux,[3] an open-source operating system, powers all of the world's supercomputers,[4] 96.3% of the one million most frequently used websites, such as Facebook and Wikipedia, and 90% of cloud services. At the same time, 72.72% of the mobile device market runs on the Linux-based Android operating system.[5] More than 80% of Internet users rely on web browsers built on Chromium[6] or Firefox, both open-source projects.[7] The Signal Protocol,[8] an open-source cryptographic protocol that enables encrypted messaging and voice communication, is used in messaging platforms such as Signal, WhatsApp, Facebook Messenger and Google Messages, serving billions of users worldwide. In the hardware sector, the success of personal computers (PCs), which spearheaded the information revolution, demonstrates the effectiveness of the open-hardware model.[9]

" Governments and corporations around the world have come to recognise that open-source is the most effective, and sometimes the only, path to technological advancement, because it enables cost-sharing.

In the context of intensifying competition with the United States and the need to close the gap with the West, the current leadership of the Chinese Communist Party seeks to implement an open model of technological development in China on a similarly large scale.[10] However, this approach is not unique to China. Governments and corporations around the world have come to recognise that open-source represents the most effective, and at times the only, path to technological advancement, as it allows for cost-sharing, more efficient use of infrastructure, computing power, and human resources, the development of compatible standards and, ultimately, the rapid and widespread implementation of innovation across the economy. Solutions developed by a global network of contributors within this model, such as software codes and hardware schematics, are made publicly available, allowing for free use, modification and redistribution. However, their commercial use is subject to certain restrictions, such as the requirement to make derivative works publicly accessible. In this respect, they differ from proprietary solutions, where access to source code and documentation remains the confidential property of a company. Proprietary solutions offer tight control over the technology used, but they are capital-intensive, while licensing increases adaptation costs and slows technological evolution. It is therefore unsurprising that open-source has become a central component of technological development strategies of major global powers, led by the United States, China, and the European Union.

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1 Originally, the term 'open-source' referred solely to software source code. Today, it encompasses the broader concept of technological decentralisation, both in terms of its development and universal accessibility. In principle, an open-source licence means that the copyright holder grants users the right to use, study, modify, and distribute a given technology freely (in the case of software, this also refers to its source code) and for any purpose. The only condition is that any innovations introduced must be shared under the same licence. The effectiveness of the open-source model is driven in large part by its community ranging from end users who report bugs to a wide spectrum of developers, from volunteers to full-time professionals, who continuously improve projects.

2 The term 'open hardware' refers to computer and electronic hardware whose specifications and design documentation are publicly available. As with open-source software, open hardware allows for the free use, modification, and distribution of designs. See 'What is open hardware?', Open Source, opensource.com.

3 S. Vaughan-Nichols, 'Linux has over 3% of the desktop market? It's more complicated than that', ZDNET, 13 July 2023, zdnet.com.

4 'Top 500. Operating system Family / Linux', top500.org.

5 'Mobile Operating System Market Share Worldwide – May 2025', Statcounter, gs.statcounter.com.

6 'The Chromium Projects', chromium.org.

7 'Web Browser Market Share: 85+ Browser Usage Statistics', Backlinko, 12 March 2025, backlinko.com.

8 'Libsignal', GitHub, github.com.

9 In 1983, IBM published the complete technical documentation and source codes for its core software, including the BIOS, of its IBM PC-XT line of computers. This allowed companies around the world to begin manufacturing IBM-compatible personal computers capable of running the same software without the need for licensing. See J. Callaham, 'The IBM PC-XT launched 40 years ago today but it got competition from the Compaq Portable', Neowin, 8 March 2023, neowin.net.

10 See Hai Sheng, '推动国产基础软件加快发展 (创新谈)', 人民日报, 1 July 2024, paper.people.com.cn.

Alternative pathways

China's delayed entry into the technological race, shaped by historical factors, has now forced it to accelerate development and adopt new solutions at a rapid pace. However, it faces a choice between two possible paths. The first focuses on developing domestic technologies that imitate or replicate those created in the United States. The second pursues an entirely different approach. Rather than seeking to 'catch up with' and reproduce American technologies, China would develop its own solutions, accepting that certain functions may be delivered differently or not achieved at all, while new ones could emerge in their place.

" The 'independent path' paradigm offers the prospect of full autonomy, not only in deploying new solutions, but also in taking the lead in their widespread rollout across the economy.

Each of these approaches has its strengths and weaknesses. The 'catch-up' paradigm ensures compatibility with solutions used in Western countries and facilitates access to many developed markets. Seeking to replicate existing solutions also makes it possible to design a research agenda geared towards achieving a known outcome or functionality while offering the possibility of 'taking shortcuts', for example through the theft of technology or intellectual property. At the same time, however, this path would confine China to the perpetual role of a 'chaser' – one that may reduce the gap with the United States and remain only a generation behind, but will never become a leader. By contrast, the 'independent path' offers the prospect of full autonomy, not only in deploying new solutions, but also in taking the lead in their widespread rollout across the economy, both at home and globally. Indeed, this approach enables the development of a self-contained technological ecosystem, one that is both independent and resilient to sanctions and restrictions imposed by the United States, currently the most prolific user of such measures. However, the 'independent path' requires greater investment in basic research, an area that typically does not yield immediate economic returns and carries a high risk of repeated setbacks.

As a result, although proprietary solutions continue to be used and developed in China, the open model appears more economically viable, both in software and hardware. It allows for the distribution of risk across multiple actors and enables direct involvement by the state, which supports specific projects rather than individual companies within the open model. Moreover, the participation of independent software developers, along with companies from around the world, provides access to global talent and expertise. At the implementation stage, this also facilitates expansion into foreign markets.

It also appears that China's superpower ambitions, along with US efforts to constrain its technological development, are increasingly pushing Beijing towards adopting an open model[11] that extends well beyond the software and open-hardware sectors. China's open-source projects now include artificial intelligence (AI) models such as DeepSeek, Ernie (Baidu) and Qwen (Alibaba). Their widespread adoption across the economy will be facilitated by the mass production of low-cost boards with AI chips based on open-hardware architecture, such as the OrangePi AIpro.[12] The openness of technical documentation is also intended to stimulate competition among component suppliers, who can simultaneously provide compatible components to various customers developing different products from individual modules. The resulting economies of scale help to maintain low prices. Chinese policymakers view the development of a robust and resilient open-source ecosystem as a means to

[11] See Jiang Xiaojuan, '以开源开放为抓手形成科技与产业新优势（人民要论）', 人民网, 31 August 2021, people.com.cn; Chi Lutung, Ji Changqing, '数字技术扩散促进数字技术创新', 学习强国, 10 September 2019, xuexi.cn; Zhao Zhuqing, Lu Qian, '重大科技成就发布会展示开源创新力量', 人民网, 26 December 2024, people.com.cn.

[12] These boards cannot be used to train AI models, but they are well suited for implementing scaled models with limited tasks. 'OrangePi AIpro', Orange Pi, orangepi.org.

drive technological progress and support the rapid, widespread adoption of new solutions across the economy.[13] The ultimate objective is to create a fully Chinese ecosystem, independent of Western intellectual property rights and restrictions, in which open-source software operates on devices built using open-source hardware.

The rise of open-source in China in the 21st century

China's first domestic Linux distribution was developed in 1999.[14] Although this alternative operating system failed to replace US proprietary solutions on a large scale, it did attract the country's first generation of open-source enthusiasts, who would later play a key role in shaping the sector's development in China. Around the same time, Chinese technical universities began introducing open-source solutions into their computer science curricula. By around 2015, mature Chinese open-source projects had begun to emerge,[15] gaining interest beyond China.[16] Since then, numerous independent and government-backed open-source initiatives have helped establish the foundations of an alternative, self-directed path for China's technological development, spanning both software and hardware, including semiconductor production and industrial robotics.

> **Security is a key argument used by Chinese leaders in promoting open-source. Therefore, in the early 2020s, the government revived its efforts to develop a domestic Linux-based operating system.**

The year 2015,[17] also marked a pivotal year in drawing the attention of CCP leaders to open-source as a means of reducing the country's technological dependence on the United States. This model, along with open technical standards, became an important part of China's development strategy and industrial policy. The central government instructed major technology companies to jointly develop open-source software for military applications, including satellite operating systems. At the local level, provincial authorities began promoting this model as a tool for optimising the digital economy. This led to the emergence of a network comprising state and public institutions responsible for overseeing the coherent development and implementation of open-source in China, while also enabling the CCP to maintain control over the entire process and steer it towards outcomes desired by policymakers.[18]

Security is a key argument used by Chinese leaders in promoting open-source.[19] In the early 2020s, the government renewed its efforts to develop a domestic open-source-based operating system (Unity Operating System)[20] with the aim of removing proprietary solutions provided by Western vendors

[13] This was first articulated in the 13th Five-Year Plan for Informatisation (2016–2020) issued by the State Council of the PRC, which encouraged the establishment of research and development units focused on open-source. See '"十三五"国家信息化规划的通知', The State Council, 15 December 2016, gov.cn. However, more specific plans were outlined later in the 14th Five-Year Plan for the Development of the Software and Information Technology Services Industry, published by the Ministry of Industry and Information Technology. See *"十四五"软件和信息技术服务业发展规划*, 15 November 2021, gov.cn; '《"十四五"软件和信息技术服务业发展规划》解读', 1 December 2021, gov.cn.

[14] Red Flag Linux was developed by Red Flag Software between 1999 and 2013. The distribution was created jointly by the Institute of Software of the Chinese Academy of Sciences and NewMargin Venture Capital. See 'Red Flag Linux', ArchiveOS, archiveos.org.

[15] In early 2025, there were around 9.4 million open-source developers in China. Huang Xin, '开源生态加速培育壮大', 人民网, 1 January 2025, people.com.cn. The Gitee (码云) repository currently hosts around 10 million projects, developed by 5 million users. See Gitee, gitee.com.

[16] C. Middleton, 'KubeCon China – how China is more open and collaborative than many believe', Diginomica, 30 August 2024, diginomica.com.

[17] The year 2015 was pivotal for the development of open-source not only in China, but also globally. See C. Metz, 'Open Source Software Went Nuclear This Year', Wired, 27 December 2015, wired.com.

[18] For further details, see *Open Source Software Country Intelligence Report – China*, OpenForum Europe, 2023, ec.europa.eu.

[19] The development of artificial intelligence is creating new security challenges, such as AI-on-AI attacks, a trend that China has recognised. See Dong Tong, Li Yuan, '深信服专家：以AI对抗AI 提升开源软件防护能力', 人民网, 8 October 2024, people.com.cn.

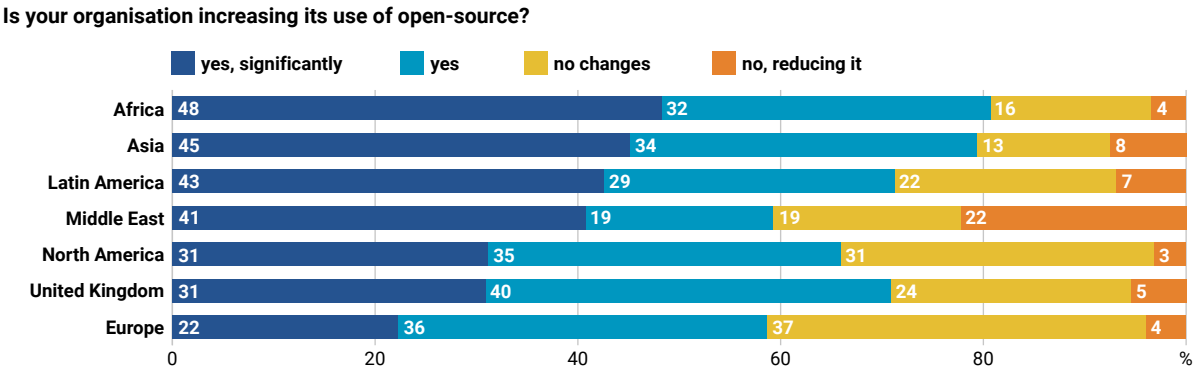
[20] 'UOS', chinauos.com.

from public administration,[21] starting with the infrastructure layer (primarily, though not exclusively, servers)[22] and ultimately extending to terminals used by government officials and for routine administrative work. Open-source code minimises the risk of successfully embedding backdoors that foreign intelligence agencies could exploit to penetrate the system, as public access to the source code greatly increases the chances of detecting such vulnerabilities. In pursuing this approach, China is drawing on the experience of the Russian Federation, which has implemented its own Linux distribution in sensitive national systems.[23]

> **Low costs are only one of several reasons that make Chinese open-source solutions attractive to countries in the Global South. As in China itself, this model has also provided them with a sense of security.**

Open-source has also become a mechanism for China to influence global technological development and position itself as a leader in key sectors. Chinese companies, such as Alibaba and Huawei, are actively involved in international open-source projects. This engagement has not only enabled them to acquire critical knowledge, skills and access to the human capital of the global open-source community, but also to influence the development of these projects and ensure that they remain accessible to Chinese industry. In fact, this exchange is reciprocal. The involvement of Chinese entities in open-source has expanded their influence within global standard-setting bodies. As a result, other countries – particularly developing ones, which are more inclined to adopt open-source solutions for financial reasons – are increasingly willing to implement those developed by Chinese actors (see Chart). In this way, open-source has become both a vehicle for China's technological expansion and a component of its broader competition with the West.

Chart. Global use of open-source software in 2023, by region



Source: 'Open-source software usage worldwide 2023, by region', Statista, 10 December 2024, statista.com.

The Made in China 2025 strategy published in 2015 marked the beginning of China's efforts to integrate open-source into its technological development plans.[24] While that document did not directly refer to open-source concepts, it called for enhancing capabilities in information technology and greater participation in standard-setting activities. The first plans to use open-source for software development, where open code is identified as the primary driver of technological innovation, were outlined in the Development Plan for the Software and Information Technology Services Industry (2016–2020),

[21] See L. Lin, 'China Intensifies Push to 'Delete America' From Its Technology', The Wall Street Journal, 7 March 2024, wsj.com.

[22] 'Document 79' requires state-owned companies in the financial, energy, and other sectors to replace foreign software in their IT systems with domestic alternatives by 2027. See *idem*.

[23] Astra Linux is an operating system being implemented in Russia to replace Microsoft Windows. It was originally developed for the Russian military and intelligence services. See 'Astra Linux', astralinux.ru.

[24] '中国制造2025', The State Council of the PRC, 9 April 2025, gov.cn.

published by the National Development and Reform Commission in 2016.[25] The first concrete action plan appeared in the 14th Five-Year Plan for the Development of the Software and Information Technology Services Industry, issued by the Ministry of Industry and Information Technology in 2021; following its publication, efforts to establish political and institutional foundations for open-source began to accelerate. Additional documents were published within the framework of the 14th Five-Year Plan, including the National Informatisation Plan[26] and the Big Data Industry Development Plan.[27] Issues linking open-source to the development of artificial intelligence were addressed in two documents: On Promoting the Use of Data to Strengthen Intelligent Cloud Computing,[28] published in 2020, and the 2021 Artificial Intelligence Standardisation White Paper.[29]

Open-source in technological competition

The open-source software market has grown rapidly in recent years. Its value is projected to rise from $41.83 billion in 2024 to $48.92 billion in 2025, with a compound annual growth rate (CAGR) of 16.9%. By 2029, it is expected to reach $90.66 billion.[30] However, these modest figures do not reflect the true significance of this model, which now dominates global information technology development – from quantum computing,[31] to the space sector.[32] According to a 2022 report by the Linux Foundation, open-source typically accounts for between 70% and 90% of the codebase used in software worldwide.[33] The relatively low value of this market[34] stems from the adopted funding structure and, paradoxically, underscores the appeal of this model resulting from its low implementation costs. Moreover, the absence of licensing fees translates into lower prices for the end user.

” Maintaining an advantage in open-source requires establishing a mechanism for stable, multi-year financing, despite limited opportunities for commercialisation. This, in turn, necessitates a high level of awareness among policymakers.

The scope of open-source application in China continues to expand as competition with the United States intensifies. Chinese companies, encouraged by the party and the state, are either launching their own open-source projects or joining international initiatives, which they later adapt for domestic use. The most significant of these appears to be RISC-V, an open processor architecture that offers a free and flexible alternative to proprietary designs such as x86 and ARM, both of which are closed architectures.[35] In the future, this could lead to the widespread adoption and decentralisation of processor manufacturing, a development comparable to the revolution triggered by the release of

[25] ‘软件和信息技术服务业发展规划 (2016—2020年)’, The National Development and Reform Commission (NDRC), 18 December 2016, ndrc.gov.cn.

[26] ‘“十四五”大数据产业发展规划’, The Ministry of Industry and Information Technology, 30 November 2021, miit.gov.cn.

[27] ‘工业和信息化部关于印发“十四五”大数据产业发展规划的通知’, The Ministry of Industry and Information Technology, 30 November 2021, miit.gov.cn.

[28] ‘关于推进“上云用数赋智”行动 培育新经济发展实施方案’, The National Development and Reform Commission (NDRC), 10 April 2020, ndrc.gov.cn.

[29] *人工智能标准化白皮书*, China Electronics Standardization Institute, 19 July 2021, cesi.cn.

[30] ‘Open Source Software Global Market Report’, The Business Research Company, January 2025, thebusinessresearchcompany.com.

[31] K. Finley, ‘Quantum Computing Is Real, and D-Wave Just Open-Sourced It’, Wired, 11 January 2017, wired.com.

[32] S. Scoles, ‘An Aerospace Coder Drags a Stodgy Industry Toward Open Source’, Wired, 24 April 2017, wired.com.

[33] J. Perlow, ‘A Summary of Census II: Open Source Software Application Libraries the World Depends On’, Linux Foundation, 7 March 2022, linuxfoundation.org.

[34] For comparison, the global software market is projected to generate revenues of $740.89 billion in 2025. ‘Software – Worldwide’, Statista, 9 April 2025, statista.com.

[35] RISC-V is an open-standard instruction set architecture (ISA) based on the principles of reduced instruction set computing (RISC). The project was launched in 2010 at the University of California, Berkeley. In 2015, it was transferred to the RISC-V Foundation, before moving in November 2019 to RISC-V International, a Swiss non-profit organisation. Companies around the world, including both American and Chinese firms, use RISC-V to design chips of varying complexity, from simple microcontrollers to advanced system-on-a-chip (SoC) solutions.

the PC architecture in 1983. In some instances, US sanctions have directly prompted a shift towards open-source. This was the case with Huawei, which developed its own Android-based mobile operating system called HarmonyOS.[36] The rise in open-source adoption is not limited to the IT sector – it also extends to industrial production. Open architectures are now being developed for both components and end products, including electric vehicles, as well as for industrial machinery, such as robots.

Low costs are only one of several reasons that make Chinese open-source solutions attractive to many actors in the Global South. As in China itself, this model has provided recipient countries with a sense of security[37] and enabled the international expansion of Chinese companies specialising in artificial intelligence.[38] Open-source code allows Beijing to reject accusations that the solutions it offers are used for surveillance, while also allowing it to cast suspicion on Western providers, who rely on proprietary software with closed source code. Combined with lingering anti-colonial sentiment, this further increases the appeal of Chinese offerings in developing countries. The rapidly growing presence of Chinese open-source solutions across the Global South also enhances China's chances of becoming a new industry pioneer and building its own technological ecosystem.

Expansion into developing markets not only enables the creation of an appealing alternative to Western solutions, but also helps to attract capital and talent from around the world.[39] This is a key factor in the technological rivalry, as many skilled and idealistically motivated developers, once engaged in preferred open-source projects that provide satisfying work and income, tend to reduce their involvement in, or lose interest altogether in, proprietary systems still favoured by many Western companies.

The open-source model also carries certain risks. The freedom to adapt and modify solutions developed within this framework facilitates competition and increases the likelihood of technology leaks from China. Preserving the leading position requires sustained capital investment, which in China's case comes primarily from the state. The returns on open-source investment are long-term and often indirect. In this regard, funding such projects resembles infrastructural investments, which typically do not generate immediate profits, but contribute to broader socio-economic development. Therefore, maintaining an advantage in this sector requires establishing a mechanism for stable, multi-year financing, despite limited opportunities for commercialisation. This, in turn, necessitates a high level of awareness among policymakers, something that poses a challenge for any political system. Actions taken by the Chinese leaders to date suggest that they understand this. Nonetheless, the question remains: how long can they continue to reconcile an open model of technological development with a closed political system?

Outlook

There is an inherent tension between the idealistic open-source community – which thrives on transparency and criticism – and the authoritarian rule of the Chinese Communist Party. Freedom of action and the questioning of established patterns have been fundamental to the success of open-source, but

[36] Huawei is a rare example of a Chinese company that continues to rely on proprietary solutions. It is currently developing HarmonyOS Next, the successor to HarmonyOS, as a closed and proprietary project. 'Huawei launches proprietary HarmonyOS for smartphones', Global Times, 16 December 2020, globaltimes.cn.

[37] One example is the popularity of language models developed by DeepSeek AI. The company has insisted that locally installed copies of its language models do not censor user queries, claiming that censorship applies only to deployments within China and results from domestic legal regulations. However, concerns quickly emerged that censorship may occur during the training phase of its language models, which would also affect their operation outside Chinese jurisdiction. See Yang Zeyi, 'Here's How DeepSeek Censorship Actually Works—and How to Get Around It', Wired, 31 January 2025, wired.com.

[38] D. Butts, 'China's open-source embrace upends conventional wisdom around artificial intelligence', CNBC, 24 March 2025, cnbc.com.

[39] Foreign software developers work remotely, with no direct exposure to conditions in China, and often naively view Chinese projects as part of transnational collaboration.

they are at odds with the CCP's instinct to dominate all aspects of economic and socio-political life. This raises the question of whether the CCP, by striving to maintain control and prevent open-source tools from being used by groups critical of the party within the Chinese population, might ultimately derail the country's technological development.[40] At the same time, mistrust of authoritarian states such as Russia and China is deepening within the international open-source community, particularly in light of repeated attempts by their security services to infiltrate it. As a result, the role of developers from these countries in shaping the future of open-source is already diminishing.

Moreover, the open-source community is not immune to international tensions: following the invasion of Ukraine, Russian developers were removed from the Linux kernel development project.[41] As open-source becomes an increasingly important element in the deepening technological rivalry between China and the United States, this dynamic will inevitably shape both the concept and functioning of this model of IT development. However, it remains difficult to predict whether, and in what ways, this will undermine the coherence of the open-source ecosystem. Despite the conflict between the West and authoritarian states, both sides need to continue their cooperation to prevent terrorist and criminal organisations from exploiting advanced open-source tools.

The technological rivalry between China and the United States is also affecting the very essence of open-source. At the same time, companies that have so far relied on proprietary solutions, such as Microsoft,[42] are now rapidly increasing their involvement in the development of this model, turning it into a new arena of corporate competition. Some firms, such as Meta, have even attempted to redefine the meaning of 'open-source', provoking resistance from the community and leading to legal disputes.[43] Other actors, including the European Union – which has created its own open-source licence (EUPL)[44] – are also seeking to shape the direction of the model's transformation and are now competing directly in this space with both China and the United States. As different open-source licences allow for varying methods of commercialisation, F/OSS licenses,[45] alongside patents, are becoming a key component of efforts to build a state's economic capacity and soft power. This is certain to further politicise the sector.

[40] In 2022, controversy erupted within China's open-source community following the announcement that all code available at the Gitee platform would be manually reviewed prior to being made public. This immediately sparked speculation that the move was linked to growing online censorship in China. See Yang Zeyi, 'How censoring China's open-source coders might backfire', MIT Technology Review, 30 May 2022, technologyreview.com.

[41] A. Das, 'No Russians in my Kernel! Geopolitics Reaches Linux Project', It's FOSS News, 28 October 2024, news.itsfoss.com.

[42] See 'Microsoft and Open Source', GitHub, github.com.

[43] S. Vaughan-Nichols, 'Why Mark Zuckerberg wants to redefine open source so badly', ZDNET, 5 February 2025, zdnet.com.

[44] 'European Union Public Licence', The European Commission, commission.europa.eu.

[45] F/OSS (Free/Open Source Software) licences grant users, under varying conditions, the right to use, modify, and distribute software. The organisation responsible for overseeing and certifying F/OSS licences is the California-based public benefit corporation Open Source Initiative (OSI). See 'OSI Approved Licenses', OSI, opensource.org.