European Commission

CHINA

CHALLENGES AND PROSPECTS FROM AN INDUSTRIAL AND INNOVATION POWERHOUSE

EUR 29737 EN

Joint Research Centre

Manuscript completed in February 2019

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EU Science Hub
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JRC116516
EUR 29737 EN

PDF	ISBN 978-92-76-02997-7	ISSN 1831-9424	doi:10.2760/445820
Print	ISBN 978-92-76-02998-4	ISSN 1018-5593	doi:10.2760/572175

Luxembourg: Publications Office of the European Union, 2019

How to cite this report: Preziosi, N., Fako, P., Hristov, H., Jonkers, K., Goenaga, X. (eds) Alves Dias, P., Amoroso, S., Annoni, A., Asensio Bermejo, J.M., Bellia, M., Blagoeva, D., De Prato, G., Dosso, M., Fako, P., Fiorini, A., Georgakaki, A., Gkotsis, P., Goenaga, X., Hristov, H., Jaeger-Waldau, A., Jonkers, K., Lewis, A., Marmier, A., Marschinski, R., Martinez Turegano, D., Munoz Pineiro, A., Nardo, M., Ndacyayisenga, N., Pasimeni, F., Preziosi, N., Rancan, M., Rueda Cantuche, J.M., Rondinella, V., Tanarro Colodron, J., Telsnig, T., Testa, G., Thiel, C., Travagnin, M., Tuebke, A., Van den Eede, G., Vazquez Hernandez, C., Vezzani, A., Wastin, F., *China – Challenges and Prospects from an Industrial and Innovation Powerhouse*, EUR 29737 EN, Publications Office, Luxembourg, 2019, ISBN 978-92-76-02997-7, doi:10.2760/445820, JRC116516.

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CHALLENGES AND PROSPECTS FROM AN INDUSTRIAL AND INNOVATION POWERHOUSE

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EXECUTIVE SUMMARY

Made in China 2025: a strategy to achieve industrial modernisation

This report analyses China's approach to attaining a dominant position in international markets through a combination of industrial, Research & Innovation (R&I), trade and Foreign Direct Investment (FDI) policies. It also offers an assessment of China's current position compared to the EU and US innovation systems across a range of dimensions.

China is rapidly becoming a major industrial competitor in high-tech and growth sectors. It aims, through the Made in China (MIC) 2025 strategy, to become a world leader in 10 key industrial sectors:

1. Next-generation IT;
2. High-end numerical control machinery and robotics;
3. Aerospace and aviation equipment;
4. Maritime engineering equipment and high-tech maritime vessel manufacturing;
5. Advanced rail equipment;
6. Energy-saving vehicles and new energy vehicles;
7. Electrical equipment;
8. Agricultural machinery and equipment;
9. New materials;
10. Biopharmaceutical and high-performance medical devices.

In these sectors, it strives to strengthen its domestic innovation capacity, to reduce its reliance on foreign technologies while moving up global value chains.

> MIC 2025 and related strategies can lead to a further deterioration of the competitive position of European firms in China

The MIC 2025 strategy aims to encourage substantial investments from national and regional governments to support domestic firms and improve knowledge infrastructures. The government intends to strengthen China's innovation capabilities and overall competitiveness by, in its own words, 'relying on market forces', though, in line with its 'socialist market economy', the state will remain central.

China is quickly gaining ground on advanced economies in high tech value chains

China's share in manufacturing global value chains has risen sharply from 6 % to 19 % in the past 15 years at the expense of the EU (whose share dropped from 27 % to 16 %), through competitiveness gains and demand factors related to the growth of the Chinese market. While EU jobs embodied in exports to China remain significantly more productive than those of China to the EU, China is gradually closing the trade-related productivity gap.

China's largest competitive gains vis-à-vis the EU are made in high-tech sectors related to computers and electronics, and electrical and mechanical engineering.

China has become a competitor in fast growing high-tech sectors to reduce its reliance on foreign based technologies

Sectoral analyses also show a rapid improvement in China's competitiveness in the nuclear field; in new energy vehicles; in wind and Photo-Voltaic (PV) technologies; in Artificial Intelligence (AI) and some parts of advanced manufacturing technologies and robotics such as drones. Heavy reliance on China for access to rare earths (crucial to wind, photovoltaics and new energy vehicles) places European industry in a potentially vulnerable position.

Developments in these domains show how Chinese companies (e.g. in solar and wind energy, robotics) can first gain domestic dominance, even with inferior technologies, by making use of protectionist measures. In a second phase, they may upgrade their technological capabilities through Research & Development (R&D), (forced) technology transfers and possibly industrial espionage. They can then expand internationally on the basis of (i) fierce price competition based on cost advantages that in some cases may result in dumping and (ii) Mergers and Acquisitions (M&As) of technologically advanced foreign companies.

The AI sector, however, is following a distinct accelerated development pattern where public sector leadership, through massive R&D funding, publicly controlled companies, innovative purchases from public authorities, favourable regulation, data policies and Intellectual Property Rights (IPR) regimes, together with a rapid international expansion and M&As by Chinese companies, may allow China to achieve its goal of becoming the world leader in AI by 2030. China could follow either or both approaches to achieve leadership in the other sectors targeted by MIC 2025.

China is rapidly expanding its control of EU firms in key sectors to capture and exploit innovative ideas

In recent years, M&As have been carried out especially in the priority fields targeted by the MIC 2025 plan. In combination with the rapidly growing venture capital investments by Chinese firms abroad, this offers a means to capture and exploit innovative ideas and companies with the potential for growth.

Such M&As are shown to stimulate the R&D investment and labour productivity of Chinese firms. FDIs by Chinese firms offer opportunities for growth in Europe, but they may also bring risks, i.e. the loss of control over strategic technologies. The exposure of Chinese banks also brings systemic risks to the global financial system.

China provides uneven playing field for European companies

While the EU currently imposes few limitations on investments by Chinese firms, the reverse is not the case for European firms investing in China. In some sectors, European firms are forced to engage in joint ventures with Chinese firms and transfer technology, including IPR. In others, FDI is blocked completely. With regards to post-entry conditions, the Chinese legal framework and unequal access to the Chinese market as well as government funding places European firms at a disadvantage compared to their Chinese counterparts.

Some improvements have been made (e.g. IPR protection), but much remains to be done to achieve a level playing field for foreign companies. Analysts fear that MIC 2025 and related strategies could lead to a further deterioration of the competitive position of European firms in China. Thus the risk is that by the time a level playing field is achieved through, for instance, trade policy negotiations, Chinese companies might have become significantly more competitive than European companies in sectors characterised by high growth and technological content, both in the Chinese and global markets.

China is the new research & Innovation powerhouse in the innovation race

R&I play a central role in China's industrial strategies given its need to improve productivity and innovation capacity in response to the upward trend in wages and the increasing requirement for technologies that cannot be easily imported or acquired through FDI. China's public and private investments in R&D have risen rapidly over the past decade.

Chinese firms already have higher R&D expenditures than their EU counterparts and are fast catching up with the US. The output of the R&I system, measured in terms of patents and high impact publications, has grown exponentially.

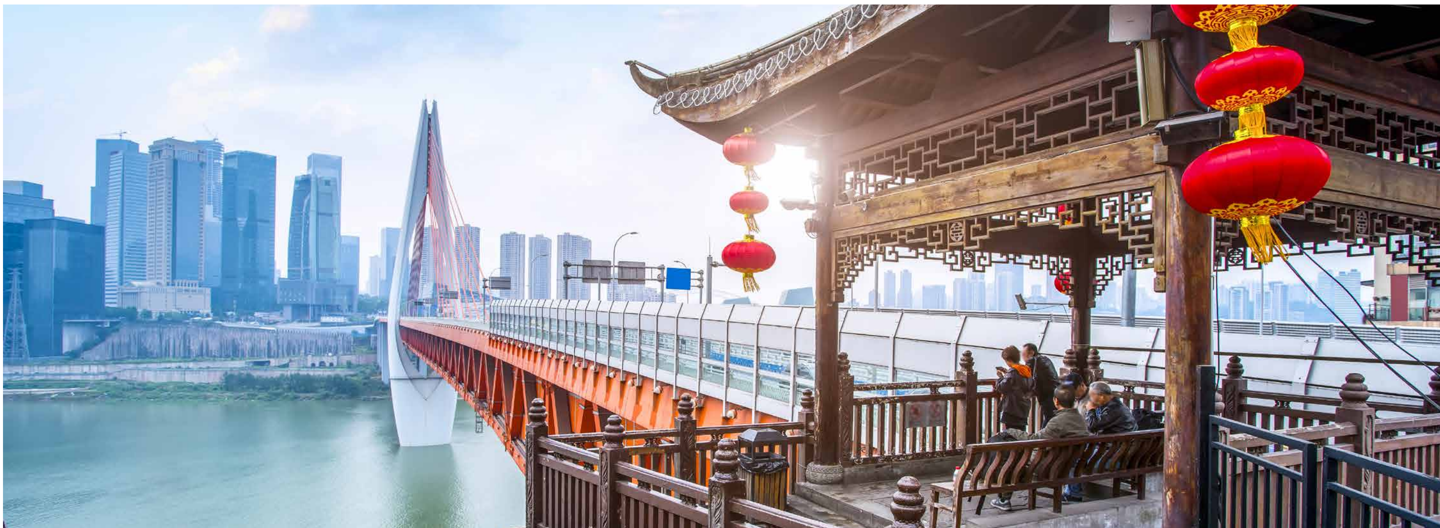
At present, China is still heavily specialised in the natural Sciences and Technologies (S&T) related to Information and Communication Technology (ICT) and micro-electronics – including areas like quantum technology. China's position in the life sciences and biotechnology remains relatively weak, but one can observe strong activity in genomics. In order to achieve the MIC 2025 objectives, China will have to broaden its S&T portfolio.

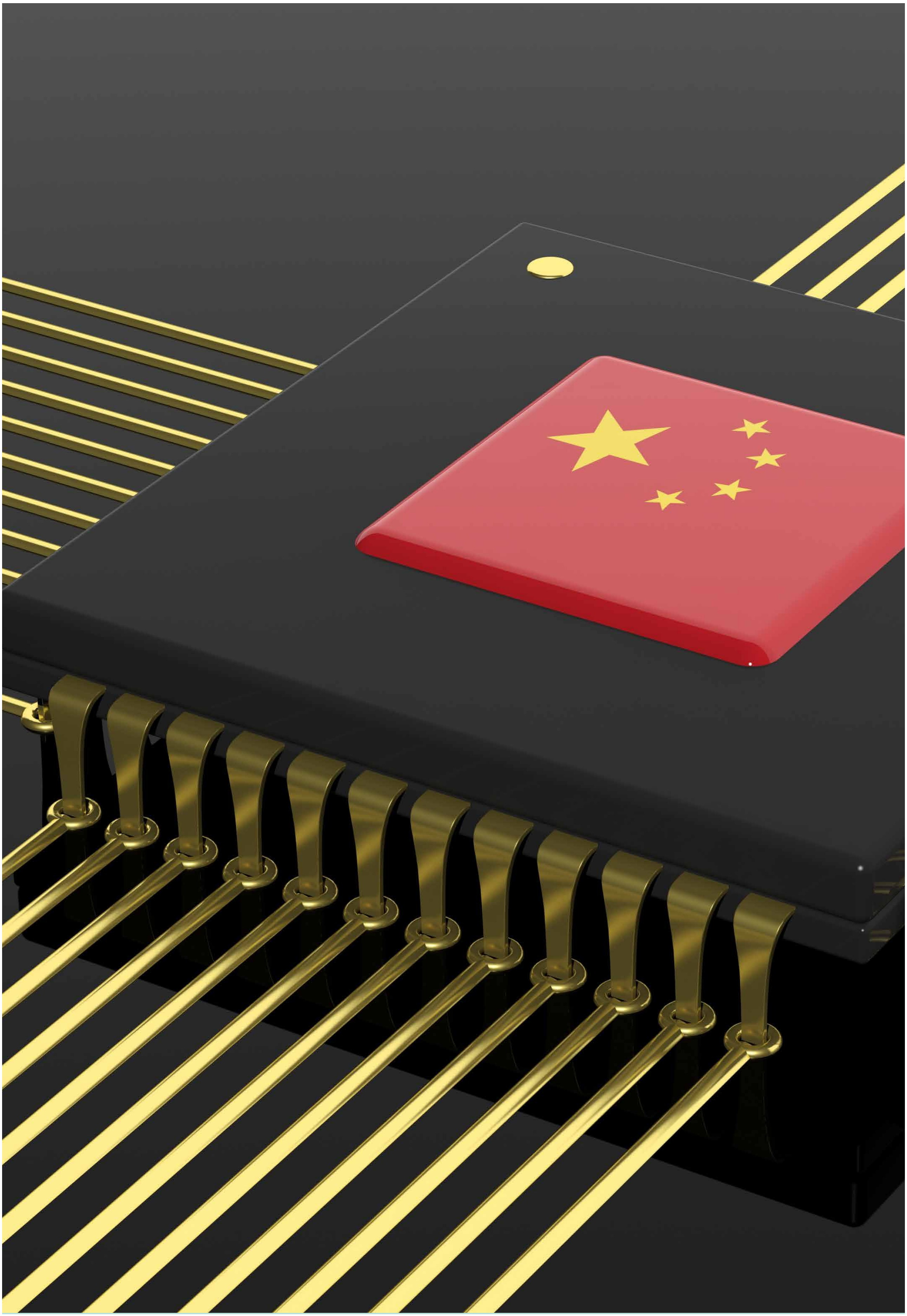
International collaboration and highly skilled mobility are playing an important role in building China's R&I capabilities. US firms and researchers benefit from a more intense interaction with China compared to their EU counterparts, which may have negative long-term implications on the relative performance of European R&I systems.

Towards 2049: China is on track to compete with the EU and US for industrial and technological leadership

A horizontal analysis of China's sectoral industrial performance shows that at present the largest gains in competitiveness are in ICT-related fields, partially as a result of FDI conditions that have favoured domestic companies. As shown by the health and pharmaceutical sectors, however, protecting local firms through FDI restrictiveness alone can be insufficient for driving international success. A competitive domestic knowledge base is also important. China's performance seems to stem from a specific and advantageous combination of productivity-enhancing investments and technology transfer from foreign sources while exploiting sheltering framework conditions.

This report concludes that China has become a major industrial competitor in several rapidly expanding high-tech sectors. The structural reforms and large investments implied by the Made in China 2025 strategy will further boost China's capabilities in the targeted high-tech fields. It may well result in China achieving its goal of becoming an innovation leader by 2049, if not well before that in specific areas. As a response, the EU will need to boost its industrial and R&I performance and develop a trade policy that can ensure a level playing field for EU companies in China and for Chinese companies in the EU. Reciprocity is crucial. Meanwhile, the EU may also want to consider the potential need for protecting strategic assets from foreign investors, be they of Chinese or US origin. In doing so, it should take into account the substantial benefits that may arise from industrial investments from abroad.





MADE IN CHINA 2025

A STRATEGY TO ACHIEVE INDUSTRIAL MODERNISATION

1.1. Smart manufacturing and a top-down focus on strategic sectors

Made in China (MIC) 2025 is a comprehensive 10-year strategy that has the aim of transforming China into a global powerhouse in high-tech industries. It focuses on intelligent manufacturing in the following 10 strategic sectors: Next-generation IT, High-end numerical control machinery and Robotics; Aerospace and aviation equipment; Maritime engineering equipment and high-tech shipping; Advanced rail equipment; Energy-saving and new energy vehicles; Electric power equipment; Agricultural machinery and equipment; New materials; Biopharmaceuticals and high-performance medical devices (Made in China 2025 – State Council, July 7, 2015). The Made in China 2025 strategy itself (Guo Fa 28) was published by the State Council in May 2015. The Implementation rules were published in March 2017, along with various accompanying measures and guidelines – for example, the evaluation of the National Innovation Demonstration Zones (NIDZs) that form a central element of the strategy.

The target year 2025 refers only to the first phase of the strategy, in which the foundations are to be laid. This involves upgrading parts of the economy and developing a (reasonable) number of world-class enterprises able to compete with companies from industrialised/Western countries (Frietsch, *forthcoming*). There are two further phases, which last up to 2049, when the People's Republic of China will celebrate its centenary. By then, China aims to belong to the top innovation-driven economies in the world. The second phase involves upgrading the whole Chinese economy – not just parts of it, or certain provinces or sectors – to a similar level, with high levels of automation and vertical integration. Horizontal integration of the industries, and an overall increase in productivity to match that of the top performers, is left to the third phase.

> China aims to be one of the top innovation-driven economies in the world by 2025

MIC 2025 is broadly in line with the German and Japanese approaches to innovation and economic development. It departs from the Strategic Emerging Industries (SEI) initiative (2006), which identified SEIs and one of the objectives of which was for them to account for 8 % of the Chinese economy by 2015 and 15 % by 2020.

These industries included renewables, alternative fuels, artificial intelligence, cybersecurity services, integrated circuits, network equipment and software, biotechnology, energy-efficient and environmental technologies, and high-end manufacturing. However, MIC 2025 is broader in scope than the SEI initiative, addressing

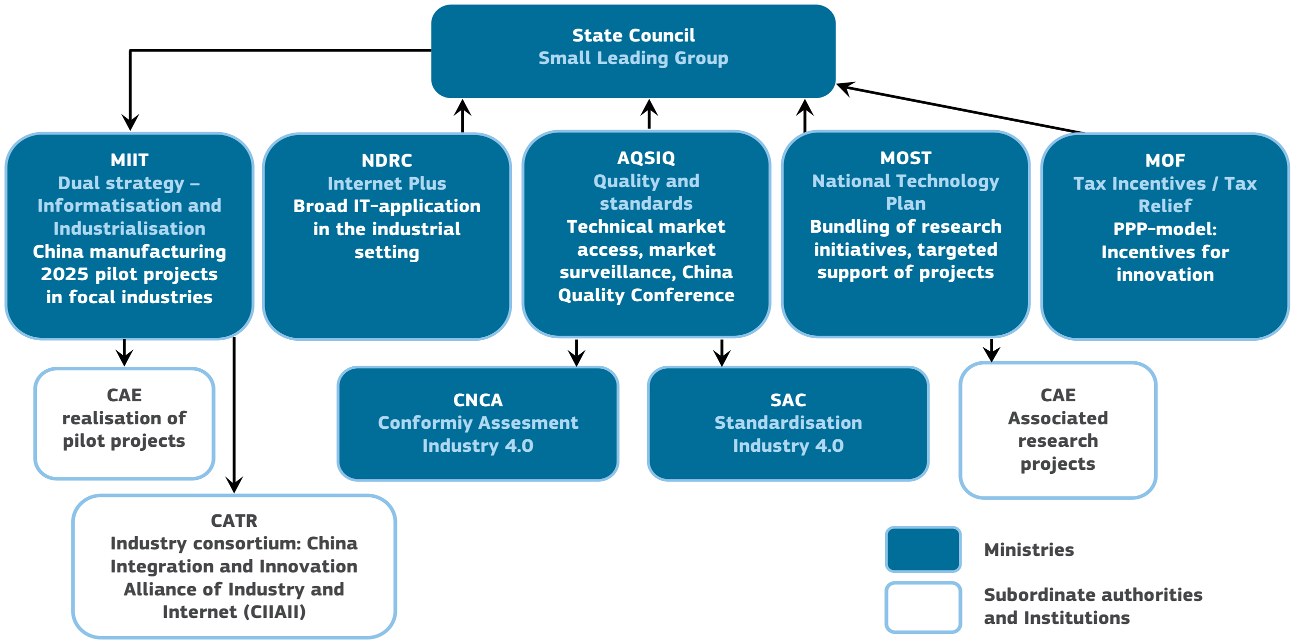


Figure 1.1: Chinese actors in the context of Made in China 2025
Source: GIZ; cf. European Chamber of Commerce in China (2017): 9.

the entire manufacturing process including traditional industries and services (Gausemeier, Klocke, 2016).

According to Frietsch *(forthcoming)*, MIC 2025 differs from almost all other policy or strategy papers by the Chinese government in that it is based on a critical and realistic reflection on the current position of Chinese industry, as well as the challenges that China faces when turning such a strategy into reality. The main challenges identified are lower product quality, less established and less well-known trademarks, high dependency on foreign high-tech, low energy efficiency and high environmental pollution, and a suboptimal industrial structure. At present, the Chinese manufacturing sector is deemed to be large but not strong. It has shortcomings in terms of innovation capacity, efficiency, quality of industrial infrastructure, quality of outputs and degree of digitalisation. To be able to address these major challenges, the three phases of the new strategy have a longer perspective than the usual 5- or 15-year plans.

The R&D-driven MIC 2025 plan is designed to be a key element in China's sustained growth and competitiveness over the coming decade, aiming to replace the country's reliance on foreign technology imports with its own innovations (Institute for Security and Development Policy, 2018). Investment is targeted towards technological innovation and smart manufacturing (e.g. machine learning, wireless sensors – key elements in next-generation IT, as well as in high-end numerical control machinery and robotics) in order to improve efficiency, quality and the productivity of manufacturing. There is a strong emphasis on domestic manufacturing processes, with the aim of improving product quality and production efficiency, increasing productivity and moving up global value chains (GVCs). Apart from competing directly with South Korea, Japan, the EU and the US, the plan also targets competition with emerging low-cost producers (e.g. Vietnam). It also focuses on the green economy, e.g. energy- and material-efficient production, and the establishment of a circular economy – key elements in energy-efficient vehicles and new energy vehicles.

In addition, MIC 2025 aims to improve the institutional structures and framework conditions in China's innovation system, in order to increase efficiency. This refers to public funding for major projects, including equipment, as well as an upgrading of major industries. Policy support will be provided through legislation and regulation, as well as investment guidelines for major industries. Furthermore, the aim is to set up a human capital and knowledge-intensive production base, with well-qualified personnel and a strong service orientation. Although public involvement is the starting point, the government emphasises its reliance on market forces to achieve the upgrading of quality and efficiency, structural reforms and improvements to the framework conditions.

1.2. Strong political leadership to implement the strategy

The responsibilities and contributions are spread between various ministerial and supporting actors. While the State Council acts as a coordinating organisation, China's Ministry of Industry and Information Technology (MIIT) is directly responsible for implementation. Other ministries make reference to MIC 2025 via their own programmes.[1] As a strong management and consultative body, the Chinese Academy of Engineering (CAE) is acting as a project management organisation, responsible for the demonstration centres and the pilot programmes.

A report by Development Solutions (2018) on behalf of the European Commission comes to the following conclusion: 'Chinese decision-makers in many cases still tend to see industrial upgrading and technological transformation as a relatively technical task of developing and installing advanced equipment, products, facilities, and infrastructures for innovation, rather than innovation of operation and management processes' (ibid: 129).

1.3. Bridging academia and industry to develop joint initiatives

MIC 2025 emphasises the role of universities and research organisations, innovation alliances and collaboration with industry. Innovation policy instruments (Frietsch, *forthcoming*) include joint research, national science & technology programmes, as well as platforms and alliances between different actors in the innovation system (companies, universities and research organisations, see also *Chapter 9)*.

Eight cities and five city clusters are acting as pilots for implementation of the policies. A total of 11 supporting plans have been drafted and a number of supporting measures have been put forward. Pilot programmes have launched new collaborations between companies, universities, and research institutes, with the aim of strengthening the application process. A status report on the implementation of MIC 2025 was released in March 2017 by the MIIT (MIIT, 2017). This indicated that 19 provincial manufacturing innovation centres and 109 smart manufacturing pilot programmes had been launched by that point. Examples include the National Power Battery Innovation Centre in Beijing, the National Additive Manufacturing Innovation Centre in Xi'an and the National Information and Optoelectronics Innovation Centre in Wuhan, which opened in April 2018. Demonstration centres are one of the main tools of the MIC 2025 strategy, as part of the approach of policy learning and establishment of best practice. The intention is to link academic with industrial research, and to develop joint standards between science and industry.

1.4. Made in China 2025 will mobilise massive investments and may favour domestic enterprises over foreign competitors

The political strategy of industrial modernisation has the potential to create enormous demand for smart manufacturing products, such as industrial robots, wireless sensor networks, and radio frequency identification chips (high-end numerical control machinery and robotics – see the 10 strategic sectors in *Section 1.1)*. This provides highly attractive business opportunities, particularly for foreign companies, given that Chinese suppliers are currently unable to provide the advanced technologies necessary. Therefore, in theory, the global economy should welcome MIC 2025, on the condition that China abides by the principles and rules of open markets and fair competition. However, according to Mercator Institute for China Studies (MERICS, 2016), MIC 2025 represents exactly the opposite: China's political leadership would systematically intervene in domestic smart manufacturing and high-tech industries, by favouring domestic enterprises over foreign competitors (see *Sections 8.3* and *8.4* on framework conditions). The rationale behind this is the two aims of MIC 2025: substituting foreign technologies with Chinese technology in domestic markets, and preparing for international market entry by domestic technology firms.

The Chinese government has set high incentives for participation in its initiatives, through massive funding and investment intentions.

According to 2017 budget allocations (China Daily, 2017), the intention is to spend CNY 10 billion (EUR 1.2 billion) on around 100 projects over the period 2018-2020. *Table 1.1* shows 'semi-official' targets (ISDP, 2018) for domestic market share of Chinese suppliers in key high-tech industry sectors. To achieve these targets, government entities are injecting large amounts of money into the system at all levels, through recently established national and regional funds. Malkin (2018) provides an estimate of these funds and their purposes as follows *(Table 1.2)*.[2] For comparison, the German Industry 4.0 initiative has so far received around EUR 200 million from the German government for research (MERICS, 2016).

1.5. Made in China 2025 could pose challenges to global trade

Two main concerns arise in relation to implementation of MIC 2025: 1) reduced market access for outsiders in China, since foreign companies among its main trading partners observe unequal treatment compared to Chinese companies in the countries of China's trading partners; and 2) an intellectual property (IP) system favouring domestic firms at the expense of foreign investors (see also *Chapter 7)*. China's foreign investment regime is considered more restrictive than that of its trading partners. In addition, strong state influence sets its political economy apart from other advanced economies. This makes it a challenge to trade with China and puts a strain on the existing global trade governance system, which Malkin sees as poorly equipped to deal with the nature of the dispute between China and its trading partners (Malkin 2018). On the other hand, from China's point of view, MIC 2025 and related policies make sense in the context of the existing global trade order.

Industry sector	Target 2020, %	Target 2025, %
High performance medical devices	50	70
High-tech ship components	60	80
Industrial robots	50	70
Mobile phone chips	35	40
New and renewable energy equipment	0	80
New energy vehicles	70	80
Tractors above 200hp and harvesters	30	60
Wide-body aircrafts	5	10

Table 1.1: Semi-official targets for the domestic market share of Chinese products
Source: Made in China 2025 - Backgrounder S&DP (2018)

Source of Funding	Total (bn €)*	Purpose/Scope
MIIT and China development Bank	37.2	Direct loans, bond sales for major MIC2025 projects
Advanced Manufacturing Fund	2.5	upgrading of low productivity manufacturing facilities into modern machine-intensive ones
State Development & Inv.	5.0	Robot- and AI-related manufacturing operations
National Integrated Circuit Fund	25.6	M&A financing in the semiconductor industry
Emerging Industries Inv. Fund	1.9	Loans for HT industry product development
Special Constructive Fund	223.1	numerous MIC2025-related projects
Shaanxi MIC2025 Fund	96.7	100 MIC2025-related projects
Gansu Made in China 2025 Fund	30.6	More than 600 projects
Anhui Manuf. Development Fund	3.6	Financing for Anhui's industrial upgrading
Nanjing Technol. Development Zone	1.1	Create a National AI Industry Base
Beijing Technology Innovation Fund	2.6	Optoelectronics, big data, new materials, clean energy, AI, adv. manuf., healthcare, IT, quantum computing
Total	**392.7**	

Table 1.2: MIC 2025 related funding by government entities
Source: Malkin (2018); *: USD/EUR=1.21 – 2018 first half average, source ECB

The European Chamber of Commerce in China described the MIC 2025 strategy as a regression to 'top-down decision-making' (ISDP, 2018). It fears that Chinese policies may 'further skew the competitive landscape in favour of domestic companies' (European Business in China Position Paper 2018/2019, EU Chamber of Commerce 2018). Furthermore, most foreign observers are worried that the import substitution goal will be achieved through market interventions strongly biased in favour of Chinese companies (MERICS, 2016). According to the Institute for Security and Development Policy (ISDP, 2018), the US government is especially concerned about advantages gained by Chinese companies in the areas of new energy, self-driving vehicles, and aerospace equipment. It considers that political backing and access to billions in funding are likely to reduce the competitive advantages enjoyed by companies and sectors in developed economies. The Trump administration is considering increasing the tariffs already introduced for China's 10 key industries, as mentioned in *Section 1.1,* together with restrictions on Chinese investments in US technology companies (ISDP, 2018). The Office of the US Trade Representative (USTR) criticised the US for supporting China's entry to the World Trade Organization (WTO) without sufficient guarantees that China's approach to international trade would be open and market-oriented (USTR, 2018a). It refers to Chinese technology transfer policies deriving from the MIC 2025 as ''innovation mercantilism' (ISDP, 2018).

The EU echoes US criticisms, especially of China's high-tech subsidies, which it deems extremely market-distorting (EC, 2017). Arguing that China is not playing a fair game (see *Sections 8.3* and *8.4* of this report), both are actively militating against granting China 'market economy' status, in order to maintain high anti-dumping duties on Chinese goods.


Current
Process
Process time

CHINA IS INCREASING ITS SHARE IN MANUFACTURING GLOBAL VALUE CHAINS

PARTICULARLY IN HIGH-TECH SECTORS

2.1. China's share in manufacturing global value chains has increased by nearly 14 percentage points (from 6 % to 19 %)

China's share in global value added in manufacturing Global Value Chains (GVC) increased by almost 14 percentage points (from 6 % to 19 %) between 2000 and 2014, whilst the EU's share fell by 11 percentage points (from 27 % in 2000 to 16 % in 2014), as seen in *Figure 2.1*.[3]

Between 2000 and 2014, the value added generated by meeting global final demand in manufacturing increased at an annual average rate of 4.6 % globally, while in the EU alone this figure was only 0.6 %. Consequently, the EU's share in manufacturing GVCs fell, by 11 percentage points, as shown in *Figure 2.1* (JRC, 2018a). This is a steeper fall than observed in the US (5.9 % decline) and Japan (3.8 % decline). The share of the other emerging countries besides China increased by 7.3 %.

The rise of China's value-added share in manufacturing global value chains is strongly based towards traditional engineering sectors

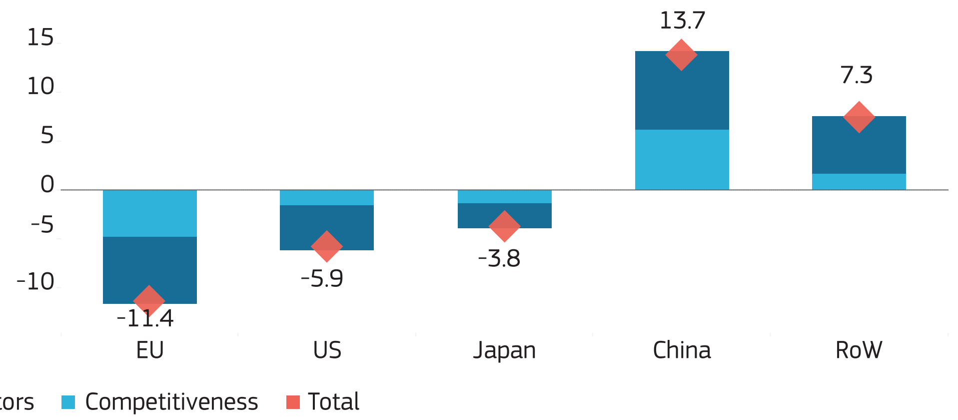


Figure 2.1: Global share in manufacturing value chains; Change in pct points, 2000-2014
Source: JRC based on WIOD (2016)

2.2. Competitiveness gains have played a large role in China's increased share in manufacturing global value chains

Factoring out demand-related factors (composition and level) shows that around 40 % of the loss in the EU's share in manufacturing GVCs – and around 45 % of China's gain – is due to changes in competitiveness *(Figure 2.1)*.

A decomposition analysis of the observed losses and gains in global shares of value added reveals that, for the EU, demand factors account for 60 % of the decline, with the EU's dependence on its low-growth home market being the main culprit. In fact, around 85 % of the value added generated in the EU, linked to manufacturing GVCs, ultimately ends up in EU final demand for manufacturing products, which grew by an average annual rate of only 0.5 % between 2000 and 2014, compared to 4.8 % outside the EU. Changes in the composition of the final demand – e.g. lower expenditure on investment and lower consumption of durable goods – also had a negative effect on the EU's value-added share.

Competitiveness factors account for the remaining 40 % – a larger contribution for the EU than for the US or Japan. They represent an overall lower retention of value added per unit of final demand due to, for example, the relocation of supply chains for EU final producers to non-EU regions, without a concomitant rise in EU participation in value chains serving final demand in the rest of the world. Although demand factors represent 55 % of the 13.7 percentage point increase in China's global share, a very significant 45 % can be attributed to its gain in competitiveness.

2.3. High-tech sectors focused on electrical and mechanical engineering show the largest Chinese increase in global value chains

Manufacturing industries are an engine of innovation, productivity growth, and exports (EC, 2017). Their importance extends well beyond the individual sectors that produce common manufacturing products like cars or textiles. On average, one euro of final demand for manufacturing products generates around 70 cents of value added outside the final producing firm, spread across many countries and economic activities, including to a large extent the service sectors. The rise of China's value-added share in manufacturing GVCs is strongly biased towards traditional engineering sectors – electrical and electronic equipment, machinery, transport equipment – as well as towards textiles.

Sector-level analyses for China reveal gains across the board, but with greater variation between sectors *(Figure 2.2)*:[4] the strongest increases can be observed in the medium-high-tech industries

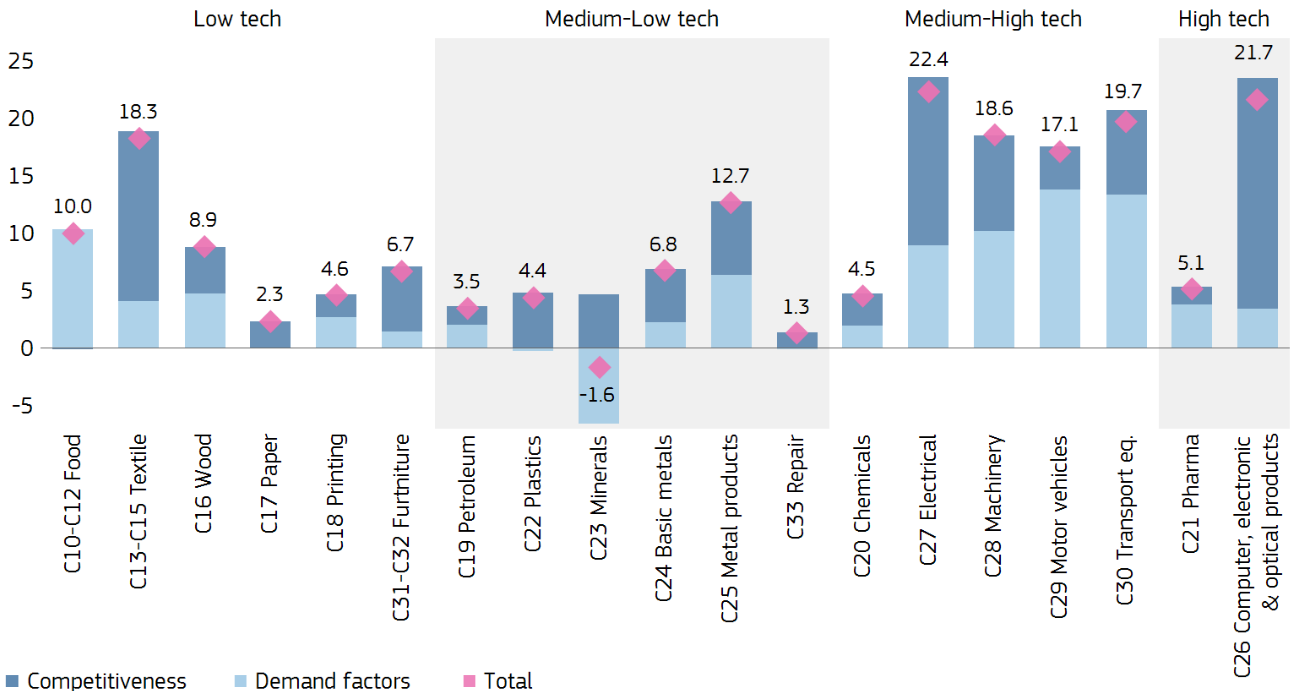


Figure 2.2: China's global value-added shares in manufacturing value chains, by sector; change in pct points, 2000-2014
Source: JRC based on WIOD (2016)

(electrical, machinery, motor vehicles and transport) and high-tech industries (electronics). China also saw a significant increase in the low-tech textile industry. China's share in the pharma and chemical sectors only increased modestly. Changes in global demand were the dominant driver of Chinese performance in the motor vehicle and transport markets, while improved competitiveness was the main reason for the good Chinese performance in the electronics and electrical industries.
The textile sector also stands out for the significant gain in competitiveness achieved by China.

The distribution of sectoral GVC gains in manufacturing seems to reflect the MIC 2025 political strategy of industrial modernisation, aimed at strengthening domestic smart manufacturing as well as medium-high-tech and high-tech industries. MIC 2025 seeks to gradually reduce the need for foreign-based technology through domestic competitiveness, to further facilitate Chinese companies' access to international markets *(Chapter 1)*.

Technological catch-up and import substitution are intended to create independent innovation and technology, with the aim of both replacing foreign competition within domestic boundaries and increasing Chinese companies' share in global markets. The MIC 2025 approach is particularly relevant to medium-high-tech and high-tech sectors such as the motor vehicles, machinery and electronics industries, as well as basic core components, materials and power equipment. Leading companies in these sectors are often already integrated in global markets and exposed to fierce competition, which sets high incentives to achieve higher productivity, product quality and production capability.

2.4. Largest global value chains losses for the EU in the low- and high-tech manufacturing sectors

All individual EU manufacturing sectors show a substantial decline at the aggregate level, with the notable exception of the high-tech pharma sector.

Figure 2.3[5] shows that a significant decrease of around 10 percentage points is seen in almost all sectors (sectors follow the NACE2 classification).

Those showing the greatest decline tend to be low-tech and medium-low-tech sectors (wood, textiles, printing) impacted by shifts in global final demand (except, notably, textiles, which shows a strong loss in competitiveness), and also medium-high-tech and high-tech sectors (electrical, electronics, transport equipment and machinery), where loss of competitiveness generally played a more important role. The one sector that is noticeable for having barely followed the overall negative trend is the pharmaceutical sector. Interestingly, China's research & Innovation (R&I) base in this sector is currently comparatively weak *(Chapter 9)*, but developments in China in the field of genomics *(Chapter 11)* and artificial intelligence *(Chapter 12)* may also threaten the position of the EU pharma sector in the long term.

In conclusion, the rise of China (and other emerging economies) has shifted the world's economic centre of gravity away from formerly dominant highly industrialised countries such as the US, Japan, and the EU. Although to a large extent a consequence of the natural economic catch-up process experienced by the developing world, it was also accompanied by a strong gain in Chinese competitiveness – and the concomitant loss in the EU's competitiveness. China's particularly strong expansion into value chains in the high-tech traditional engineering sectors suggests that it is steering towards a role as a technological leader – which could challenge the primacy of the US and the EU in particular.

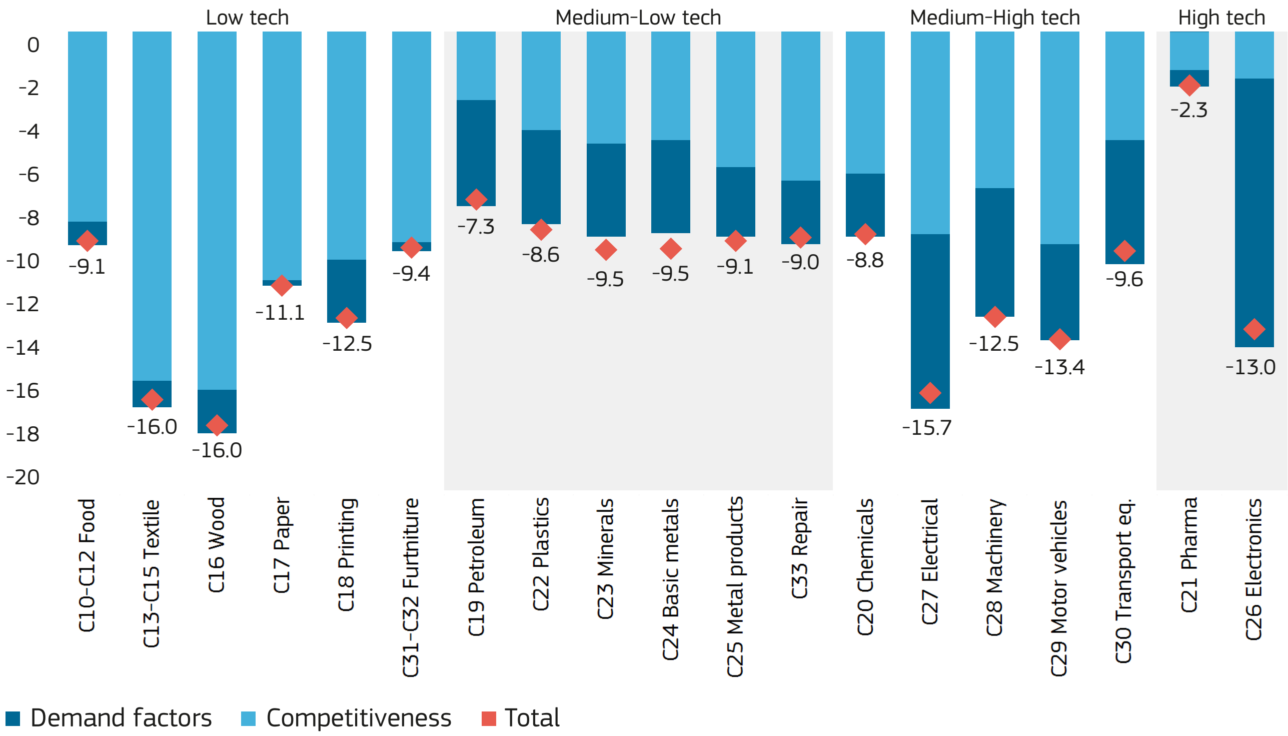


Figure 2.3: EU's global value-added shares in manufacturing value chains, by sector; change in pct points, 2000-2014
Source: JRC based on WIOD (2016)

EU JOBS EMBODIED IN EXPORTS TO CHINA ARE STILL MORE PRODUCTIVE

3.1. EU exports to China increased almost sevenfold from 2000 to 2014

> Chinese labour productivity for its exports to the EU grew by a factor of 3.3 between 2000 and 2014

In 2014, EU exports to China were 6.6 times higher than in 2000 in value-added terms, and nearly seven times higher in gross terms; while Chinese exports to the EU, both in value-added and gross terms, were 6.1 times higher *(Figure 3.1)*.[6]

In terms of manufacturing industries, EU high-tech manufacturing sectors saw their share of value added accrued in EU exports to China decrease from 57.4 % in 2000 to 54.8 % in 2014. Conversely, Chinese high-tech manufacturing sectors saw a remarkable increase in their share of value added embodied in Chinese exports to the EU (from 38.7 % in 2000 up to 50.6 % in 2014). Similar conclusions can be drawn for respective EU and Chinese exports of goods and services for final use, but not for EU intermediate exports to China. The EU value-added share in high-tech manufacturing sectors remained relatively stable for intermediate exports to China.

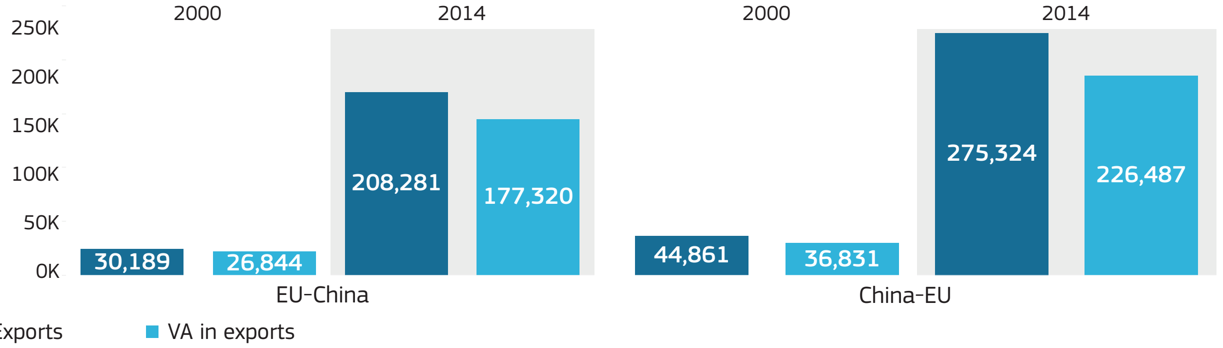


Figure 3.1: Bilateral trade in gross and value-added terms (2000-2014)
Source: JRC based on WIOD (2016)

For services, there was a common pattern for exports of both intermediate and final services: an increase in the EU value-added share in EU services exported to China, particularly in tradable services where there was a remarkable increase in logistics (trade, transport and accommodation) and business services, to the detriment of other non-tradable services; and a reduction in the Chinese value-added share in services exported to the EU (20 % in 2000 and 14 % in 2014), mainly in other non-tradable services.

In 2014, 85 % of the value of gross EU exports to China was retained by EU firms (down from 88.9 % in 2000)[7] while in China this was slightly over 82 % (as in 2000). The remaining 15 % represents value added generated in other non-EU countries, driven by EU exports to China.

There was enormous growth in bilateral trade between the EU and China during this period, and also in the trade deficit. In value-added terms, the EU's trade deficit increased to EUR 49.2 billion (from EUR 10 billion in 2000) while in gross terms it increased to EUR 67 billion (from EUR 14.7 billion in 2000).

3.2. EU imports from China in 2014 supported 19 million more jobs than Chinese imports from the EU

The employment results not only include employment directly linked to the exporting industries, but also other indirect employment associated with their supplying industries.
In 2014, EU imports from China supported 21.5 million jobs in China, while Chinese imports from the EU supported 2.6 million jobs in the EU. This difference has increased by 4.4 million jobs since 2000. These differences can be explained by: (a) the product mix of goods and services exported between China and the EU (i.e. more or less high-tech-orientated); (b) differences in labour intensity in the production of these exports; and (c) differences in productivity between the two economies. Furthermore, the share of total EU employment linked to its exports to China rose from 0.3 % to 1.1 %, a much higher growth in relative terms than in China (from 2.1 % in 2000 to 2.5 % in 2014).

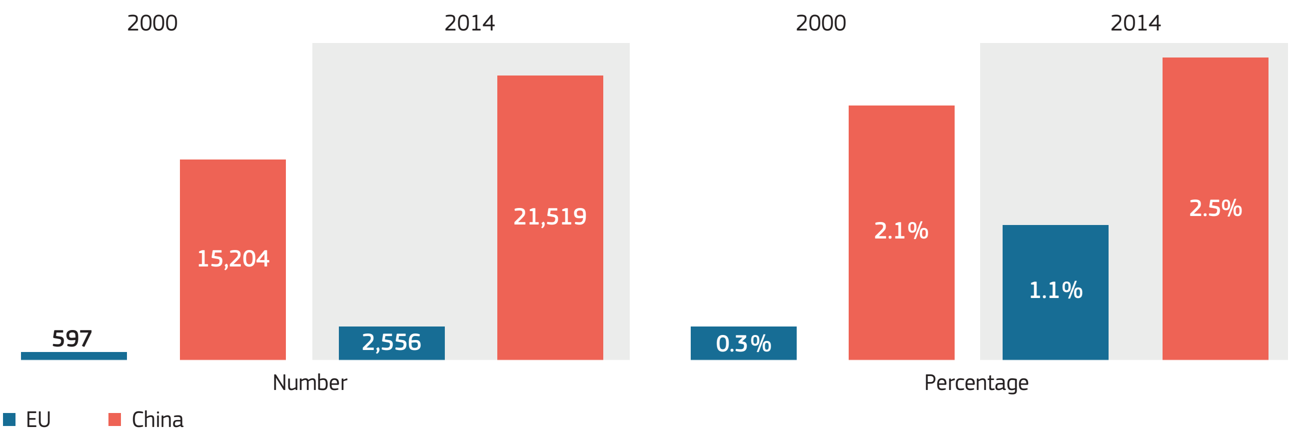


Figure 3.2: Employment content of EU and Chinese bilateral exports (2000-2014); jobs and % of national total employment
Source: JRC elaboration from WIOD (2016)

3.3. EU jobs embodied in exports to China are 6.6 times more productive than Chinese jobs embodied in exports to the EU

Figure 3.3 shows the relationship between EU and Chinese bilateral exports in value added, and the national employment supported by these exports. Labour productivity content is measured as the value added per unit of employment. It is noteworthy that the labour productivity content for the EU jobs amounted to EUR 69 368 per job in 2014, while for Chinese jobs it was just EUR 10 525 per job. In short, EU jobs embodied in exports to China are 6.6 times more productive than Chinese jobs embodied in exports to the EU.

respectively), although these were not significant enough to counteract the overall increase in the productivity gap between the EU and China. Furthermore, empirical evidence shows a shift in EU exports to China, from intermediate exports to exports for final use, while the exact opposite is true for Chinese exports to the EU. This could be interpreted as upgrading processes happening in parallel in the EU and China, but at different production stages. Generally, higher value-added shares per unit of output are found in production processes closer to the final stages of production (Ye, Meng and Wei, 2015).

Following the literature on the relationship between factor reallocations and international competition

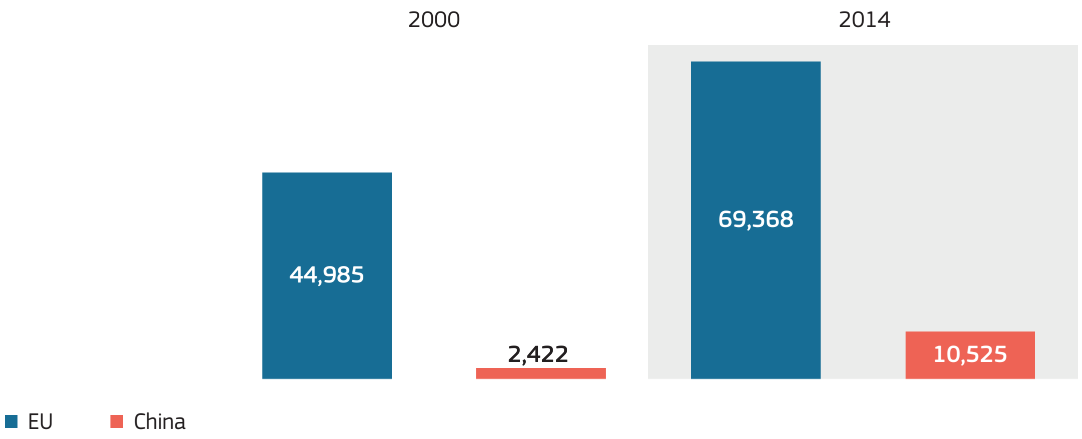


Figure 3.3: Labour productivity content of EU and Chinese bilateral exports (2000-2014)
Source: JRC elaboration from WIOD (2016)

However, it should also be noted that Chinese productivity for its exports to the EU grew by a factor of 3.3 between 2000 and 2014, while the EU's productivity for its exports to China increased by just 54 %. Moreover, there has been an increase in the EU trade-related total productivity gap (+EUR 16 281/job) with respect to China over this period (from EUR 42 562/job in 2000 to EUR 58 843/job in 2014). This was much more pronounced in EU high-tech manufacturing sectors (EUR 7 775/job), logistics (EUR 5 588/job) and business services (EUR 3 263/job) - typically from more downstream production stages. However, finance and other non-tradable services saw productivity losses (EUR 211/job and EUR 2 861/job,

(Melitz, 2003; Melitz and Ottaviano, 2008), the high employment content and productivity embodied in Chinese exports might imply that, alongside the process of Chinese industrial development and transformation, workers have been steadily reallocating across firms in highly productive sectors or sectors with better technologically endowed firms. Similarly, Autor et al. (2013) and Bloom et al. (2016) also showed how China is rapidly improving in terms of the labour productivity embodied in its exports with respect to the US and the EU, respectively. In such a scenario, workers would be leaving those firms less capable of resisting international competition and moving to those better able to reap the benefits of trade.

	2000	2014
European Union		
EU exports to China (gross)	30,188.70	208,281.30
EU exports to China (in value added terms), million EUR	26,844.10	177,320.10
Employment embodied in EU exports to China, th. Jobs	596.70	2,556.20
Embodied productivity EU-China (value added/employment) - EUR/job	44,984.51	69,367.65
EU exports to the World (gross)	1,219,647.60	2,523,761.20
EU exports to the World (in value added terms), million EUR	1,078,448.80	2,115,873.80
Employment embodied in EU exports to the World, th. Jobs	21,658.80	32,464.10
Embodied productivity EU-World (value added/employment) - EUR/job	49,792.64	65,175.80
China		
Chinese exports to the EU (gross)	44,860.80	275,324.00
Chinese exports to the EU (in value added terms), million EUR	36,831.20	226,487.30
Employment embodied in Chinese exports to the EU, th. Jobs	15,204.00	21,519.30
Embodied productivity China-EU (value added/employment) - EUR/job	2,422.46	10,524.85
Chinese exports to the World (gross)	283,605.50	1,825,716.50
Chinese exports to the World (in value added terms), million EUR	236,310.00	1,518,037.50
Employment embodied in Chinese exports to the World, th. Jobs	99,107.60	145,257.70
Embodied productivity China-World (value added/employment) - EUR/job	2,384.38	10,450.65
Trade balance		
EU trade balance with China (gross)	-14,672.20	-67,042.80
EU trade balance with China (in value added terms)	-9,987.00	-49,167.20

Table 3.1: Summary of Results
Source: JRC elaboration from WIOD (2016)

As can be seen from the disparities between the EU and China, the potential employment creation due to higher productivity is considerable. Besides participation in international markets, access to supplies of inputs from abroad might have been a precondition for such a phenomenon whose gains are now in the process of being internalised through the MIC 2025 strategy which is aimed at reducing China's dependence on foreign markets.

3.4. China's rise in net exports is reducing its dependence on foreign markets for key industries

Comparing revealed comparative advantages in net-export terms[8] between the periods 2008-2010 – when the Chinese State Council released an economic stimulus package in response to the global financial crisis to support the economy though infrastructure investments – and 2014-2016 reveals a significant expansion of the Chinese manufacturing industry in many fields.
This is the case in particular in those related to chemical products such as inorganic basic materials or scents and polish, and, within mechanical engineering fields, power machines, special purpose machines and particularly rail vehicles show positive developments *(Figure 3.4)*.

Only a few industries such as biotechnology and medical instruments display a lower score during the period 2014-2016 with respect to the years 2008-2010; the majority show improvements, particularly power generation and distribution, rail, optical devices, nuclear, mechanical measurement and special purpose machinery. These trends suggest how Chinese firms – including foreign-owned companies producing in China – appear to have become more competitive in international markets in most areas. These results are in line with the MIC 2025 general objective of becoming less dependent on international products (imports) and instead develop key national industries. This goal seems to originate from the post-financial crisis awareness of the need for a transition from an overly export-oriented model that cannot respond well to systemic shocks when its core strength has a relatively restricted focus.

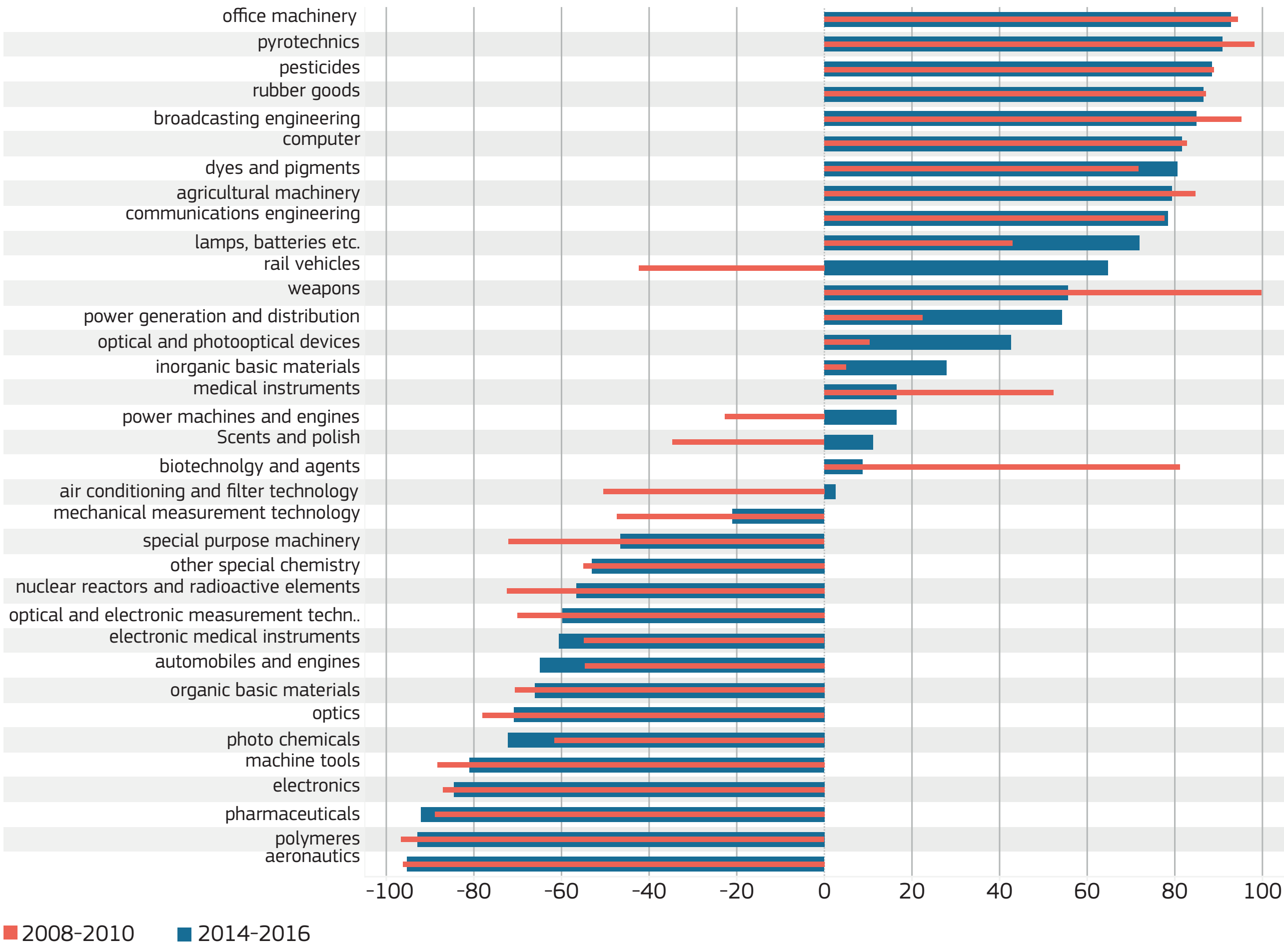
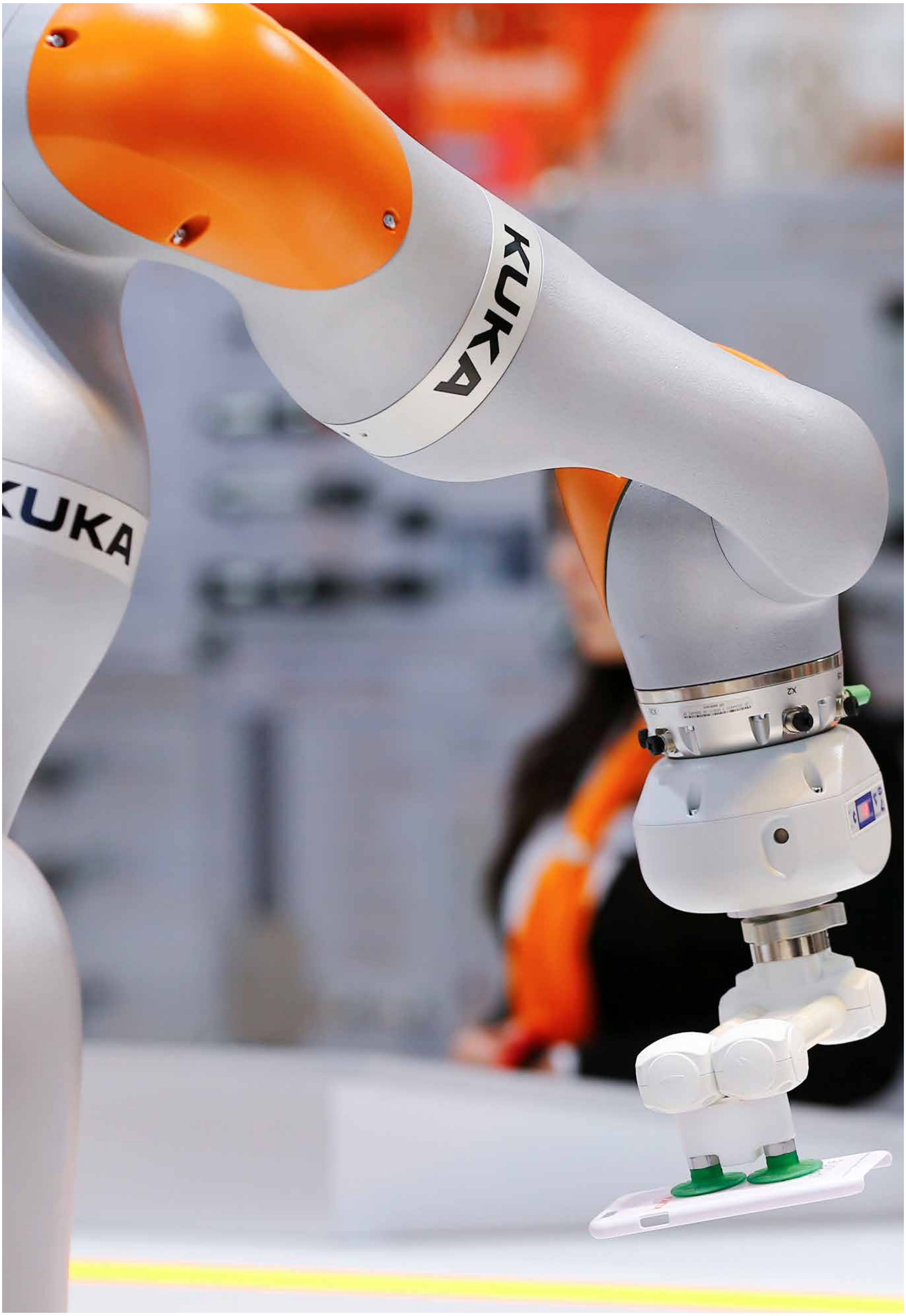


Figure 3.4: China's Revealed comparative advantage (Export - Import relation); (index normalised to 100); (2008 - 2010) versus (2014 - 2016)

Source: UN - COMTRADE; based on Frietsch *(forthcoming)*


KUKA
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CHINA INCREASINGLY CONTROLS FIRMS IN THE EU

4.1. China is overall the largest exporter of capital since the 2000s

Over the past decade, Chinese central and local governments have attracted new manufacturing facilities by offering all kinds of financial subsidies, helping firms to get cheap loans from state-owned banks, and by favouring decreases in operating costs and expansion in production[9]. The Chinese recipe for fostering growth and reshaping the industrial landscape also saw an improvement in Chinese industrial leadership abroad, in line with the China Going Global strategy. China encouraged overseas investments as a means of reaching new technologies, improving domestic supply chains and paving the way for increased exports of Chinese goods. Since the start of the century, China has been the largest exporter of capital, accounting for about USD 3 trillion over the period 2004-2016. According to estimates by the EU-China FDI Monitor (Rhodium Group), Chinese Foreign Direct Investment (FDI) in the EU-28 amounted to EUR 65 billion in 2016-17; roughly double that in 2014-15. This trend is not likely to slow down: at the 2017 World Economic Forum in Davos, Chinese President Xi Jinping announced planned outward investments of EUR 670 billion over the next 5 years.

> Chinese firms invest in high-tech manufacturing, including robot-assisted production for the automotive, health and energy sectors

Figure 4.1 shows an overall increase in the number and value of Chinese cross-border M&A deals in the EU and the US since 2009, with the largest shares directed towards the EU in most years. Two features of cross-border acquisitions, in particular, have received increasing attention. First, there is the concern that these acquisitions give Chinese firms an edge in global markets and may result in potential negative implications for growth elsewhere. Second, although M&As

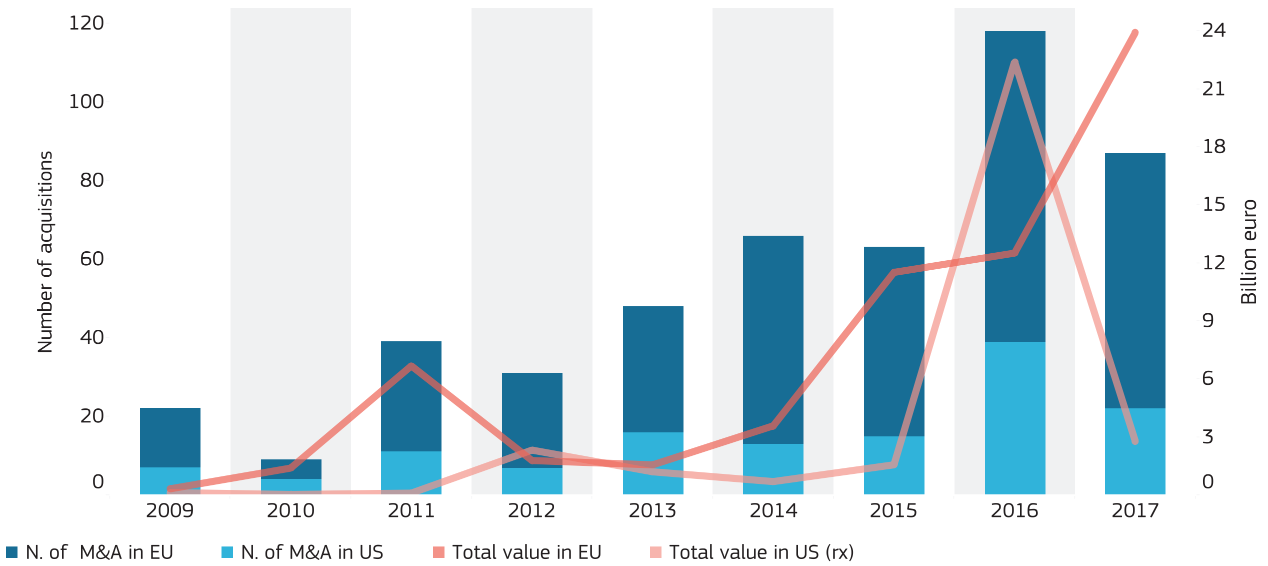
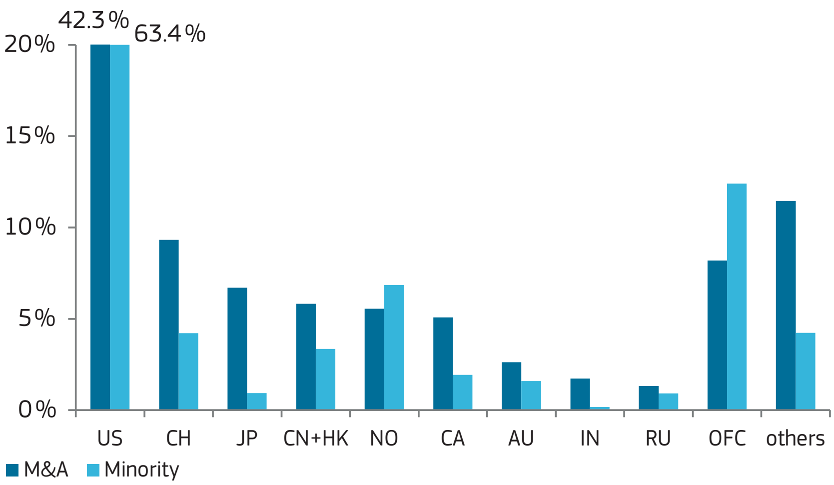


Figure 4.1: Chinese cross-border mergers and acquisitions (M&As) in EU and US

Source: JRC calculations based on Bureau van Dijk data (Zephyr and Orbis) for a sample of EU and US firms, shared across datasets to increase cross-reliability of deals and balance sheet data. Note: The aggregate value of the M&A deals is only indicative as many of the deals do not report the value.

are considered an important driver of corporate performance, there is a concern that, regardless of the nationality of the acquirers, such acquisitions may reduce competition[10], which in turn has a negative correlation with corporate performance. Interestingly, both the number and total value of Chinese M&A deals towards the US and EU dropped substantially in 2017 with respect to the previous year. The number of M&A deals towards the US was almost half that of those towards the EU in 2016 and one third in 2017. This may reflect increasing restrictions on Chinese investments, particularly on the part of the US, in sensitive sectors.

An overall picture of Chinese stakes in the European Economic Area, both in terms of firms and assets controlled, is broadly lacking. For this reason, the JRC has reconstructed the ownership structure of EU firms controlled from outside Europe for the period 2007-2016 (including recent M&A data and data on minority stakes in EU firms). Raw data



% change with respect to previous 5y	M&A	Minority
CN	126.0	62.1
HK	30.8	144.1
JP	-8.1	2.0
CA	-12.0	90.9
AU	-13.9	-58.5
NO	-16.6	101.9
CH	-22.6	-27.0
US	-25.8	203.4
IN	-42.1	-42.4
RU	-51.1	11.2
OFC	-29.8	287.4
others	-21.0	13.1

Figure 4.2: Foreign M&As and minority stakes in European firms

Source: JRC computations on foreign ownership database. Left panel: share of foreign investments in EU28 (M&A and minority stakes) by origin of the investing partner, period 2015-2018q2. OFC stands for offshore financial centres, defined according to IMF (2014). Right panel: percentage change of M&As and minority stakes in EU28 in 2015-18q2 with respect to the previous five years (2010-14).

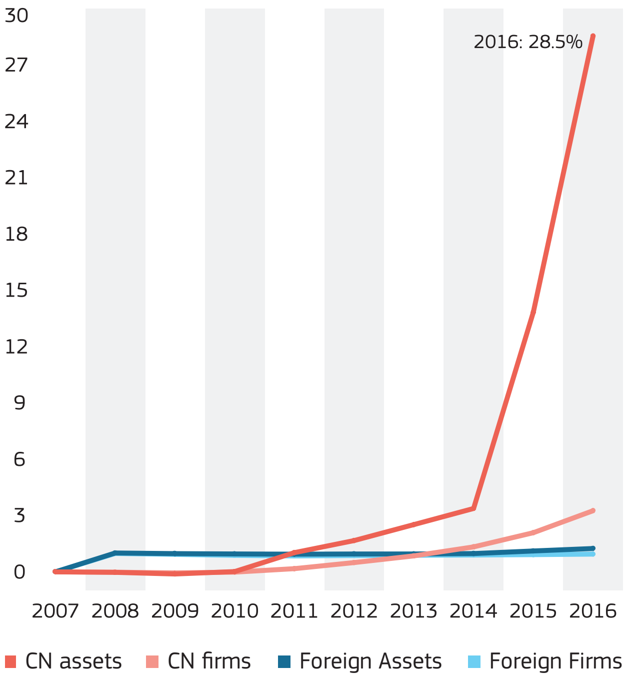


Figure 4.3: Chinese and Hong Kong stakes in Europe; Growth (%, 2007=0)
Source: JRC computations on foreign ownership database. Note: growth is computed from the share of EU firms controlled by China with respect to total number of firms active in EU. Foreign stands for total EU28 firms controlled by non-EU partner excluding China. Growth rates are calculated with a moving average of three years. The graph is cut at 15% to show small changes. Chinese growth in purchased assets (as compared to 2007) is 13.8% in 2015 and 28.5% in 2016.

are based on Moody's Bureau van Dijk (BvD) Orbis data. Data on M&As are from BvD Zephyr. M&A data have been matched with ownership data to retrieve the ultimate owner of the firm at the moment of the investment. Both mainland China and Hong Kong have been considered, the latter being the international gateway to and from China. Hong Kong's rule of law, openness and integration in the global financial and economic system attract global capital into, and move Chinese money out from, the mainland. Among the 47 000 companies registered in Hong Kong and reporting ownership information, about 16 % have an ultimate owner in China. The reverse also holds true, with about 3 200 Chinese firms reporting an ultimate owner in Hong Kong.

4.2. The number of EU firms controlled by China has increased rapidly, from 1.4 % of foreign-controlled firms in 2007 to 8 % in 2015-16

According to the JRC analysis, China and Hong Kong rank fourth after the US, Switzerland and Japan in terms of the share of M&As in the period 2015-2018q2 *(Figure 4.2, left panel)*.

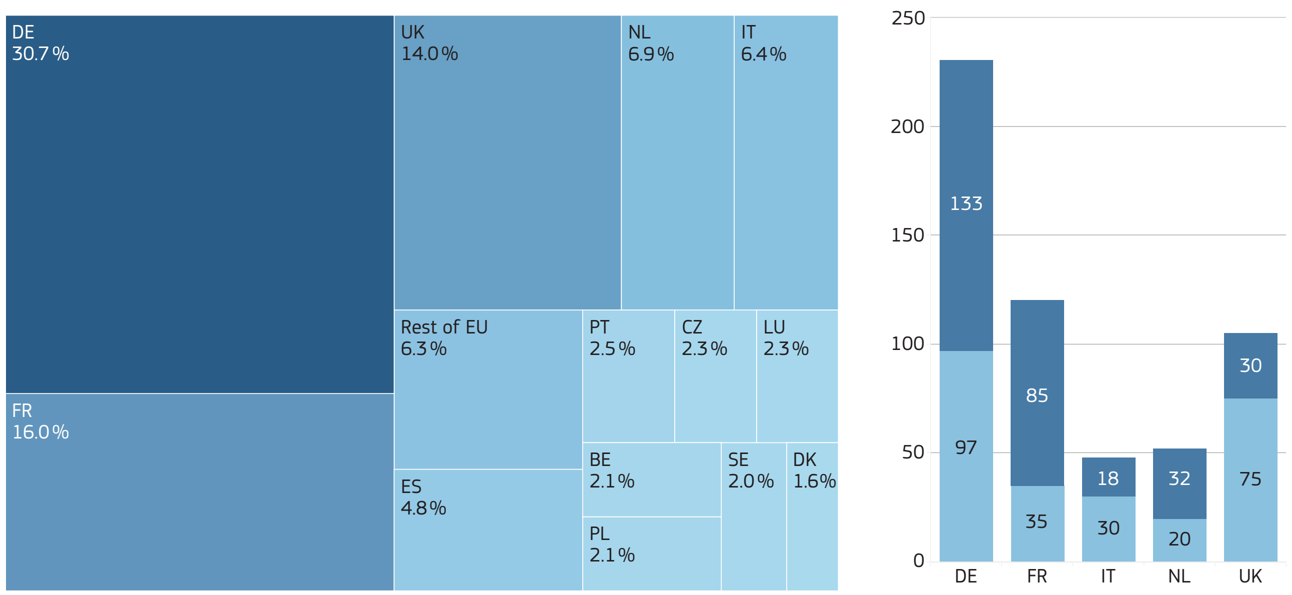


Figure 4.4: Chinese and Hong Kong investments (M&A and minority stakes) in Europe by country of the acquired firm
Source: JRC computations on foreign ownership database. Czech Republic (CZ), France (FR), Germany (DE), Italy (IT), Netherlands (NL), Poland (PL), Portugal (PT), Spain (ES), Sweden (SE), United Kingdom (UK). Rest of EU includes all EU28 except those explicitly mentioned in the graph.

For this period (as compared to the previous 5 years), all the main foreign investors in Europe decreased their investments, with the notable exception of China (+126 %) and Hong Kong (+31 %) *(Figure 4.2, right panel)*. The role of OFCs among the main investors is increasing, especially for minority investment stakes. The stock of Chinese investments in Europe is approximately 8 000 firms in 2015-16, representing 8 % of EU firms with a foreign owner (1.4 % in 2007).

China is increasingly controlling firms with a high market share (proxied with assets[11]) compared to other non-EU investors *(Figure 4.3)*. The target countries for their investments have tended to be the largest EU countries in terms of GDP, i.e. Germany and the UK with 25 % and 19 % of M&As respectively, followed by France, Italy and the Netherlands *(Figure 4.4)*. Germany and France are the countries attracting the highest share of minority stakes, with 36 % and 23 % respectively. The vast majority of Chinese investments in the EU are made through M&As. By contrast, greenfield investments, with high potential for job and growth creation, are limited in volume – they represent barely 5 % of the total (RHG EU-China FDI Monitor, MERICS, 2018).

4.3. Chinese investments in Europe increasingly target strategic sectors, particularly manufacturing and ICT companies based in Germany

Sectoral diversification of Chinese and Hong Kong corporate control in Europe *(Figure 4.5)* shows progressive widening of Chinese interests in the last decade and a shift from wholesale and retail towards manufacturing. In 2007, wholesale accounted for 57 % of Chinese stakes in the EU-28. By 2015, this share had dropped to 37 %, and a further decline can be seen when looking at M&As over the period 2016-2018q2. China's presence in manufacturing accounted for 9 % of all Chinese-controlled firms in 2015 but more than 36 % of M&As over the period 2016-2018q2. Chinese firms tend to invest in high-tech manufacturing, often including robot-assisted production of components and machinery for the automotive, health and energy sectors. Especially relevant are the M&As involving electric and hybrid vehicle technology, advanced solutions for solar and wind power production, and equipment for water treatment and sanitation.

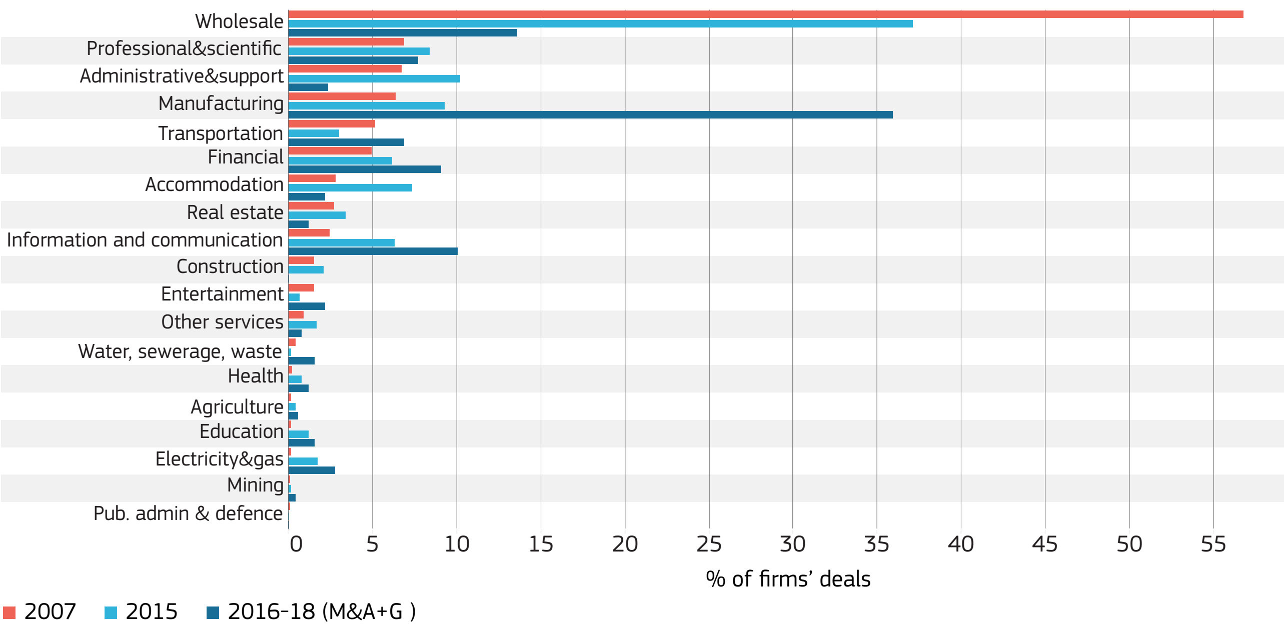


Figure 4.5: Foreign controlled firms in the EU28: Chinese and Hong Kong stakes by sector of investment

Source: JRC computations on foreign ownership database. Note: the picture shows the percentage of firms by sector of economic activity, controlled by China and Hong Kong in 2007 and 2015 and the number of M&A deals and greenfield investments done by Chinese and Hong Kong investors in the period 2016-2018q1.

R&D-related companies (classified under 'Information and Communication' and 'Professional and Scientific Activities' sectors) accounted for 15 % of all Chinese-controlled firms in Europe in 2015 (10 % in 2007) and 18 % of recent M&As. *Figure 4.5* shows a growing presence of Chinese-controlled firms in manufacturing, ICT, transportation (linked to the Belt and Road Initiative) and the financial sector (e.g. banks and insurance companies in the UK, Belgium and Portugal). China's role remains marginal in mining and in agriculture, in part because extraction technologies and agricultural vehicles, which are indeed a target for Chinese takeovers, are recorded in other industrial sectors.

The Made in China 2025 strategy provides a clear plan for Chinese overseas investments. Since 2015, about one third of all Chinese investments in Europe (be they M&As or minority stakes) have been in the sectors specified in the MIC 2025 strategy (see *Chapter 1)*. The lion's share of the takeovers are in next-generation IT and in transportation, followed by numerical control machinery and robotics, and new materials *(Figure 4.6)*. The countries most involved have been Germany (accounting for 46 % of takeovers related to MIC 2025), followed by the UK (13 %) and Italy (9 %).

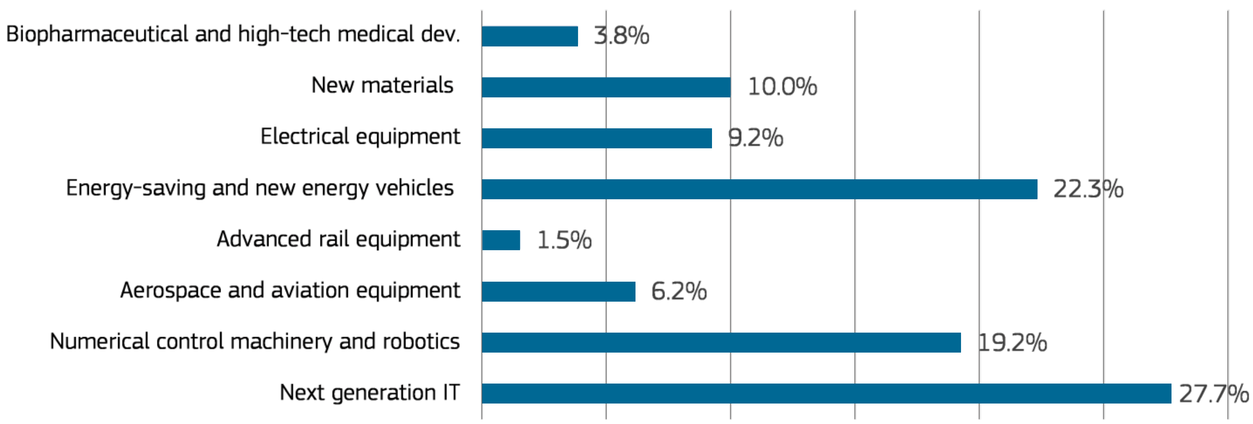


Figure 4.6: Chinese investments in Europe related to Made in China 2025 by sector of the acquired firm
Source: JRC computations on foreign ownership database. Period: Jan 2015 - Aug 2018

China's infrastructure gap

The Asian Development Bank estimates investment needs of USD 9.3 trillion for transport, USD 12.3 trillion for electricity generation capacity and USD 6.5 trillion for sanitation and water source development, to bridge the gap between China and OECD countries (Asian Development Bank, 2017).

The large volume of outward investments is related not only to infrastructure projects but also to arbitrage conditions. Over the last decade, the state-granted access to cheap capital, designed to help Chinese firms to invest domestically, also increased the incentive to invest abroad, which provided a much higher rate of return. Europe experienced Chinese investments, e.g. in the French vineyards of Chateau Mirefleurs and Loudenne, in olive groves in Italy, football teams everywhere (West Bromwich in the UK, Español and Granada in Spain, Slavia Pra`ha in the Slovak Republic, Milan in Italy), Club-Med in France and real estate in the UK. The belief that the state would bail out debts from large and bad investments also increased 'irrational' investments. In late 2016, the Chinese government limited outward investments by revamping pre-approval requirements and revising the list of prohibited and restricted overseas investments. Major players who tried to bypass these limits were apprehended; for example in February 2018, the large insurance company Anbang was de-facto nationalised and its boss prosecuted.

4.4. Post-acquisition changes in productivity are larger for Chinese acquiring firms than for their EU or US counterparts

Given the rapid increase in M&As by Chinese-owned firms, there is concern that these acquisitions will give Chinese firms an edge in global markets, to the detriment of European competitiveness. Analysis of acquirers' performance post-acquisition indicates that cross-border M&As overall lead to higher labour productivity, sales growth and labour productivity growth for the acquirers (even allowing for size, industry and country characteristics). *Figure 4.7* shows that post-acquisition increases in acquirers' productivity levels, sales growth and productivity growth rates are largest for Chinese firms acquiring EU or US manufacturing companies. On average, a Chinese company acquiring an EU or US company sees a positive change in labour productivity of 14 %. Note: The marginal effects of M&As refer to the percentage change in the performance measure, by acquirer. Patterned coloured bars indicate that the result is not statistically significant at the 90 % confidence level. Although the reported marginal effects are not strongly statistically significant for labour productivity growth, the results across the different performance measures present a similar trend.

In general, M&As lead to better firm-level performance, only where the industry is not too concentrated *(Figure 4.8)*. If no firms from the EU, China or the US had made any acquisitions, their sales growth would be 10 % at any level of concentration. On the other hand, if all firms had performed acquisitions, their sales growth would be around 17 % for a low level of concentration and around 13 % for a high level of concentration. Labour productivity growth, in particular, is more sensitive to less competition, as the marginal effect of M&As already decreases at a medium level of industry concentration. Theoretically, a more concentrated industry may reduce incentives to introduce new innovative products, due to less competitive pressure, thereby resulting in lower firm performance.

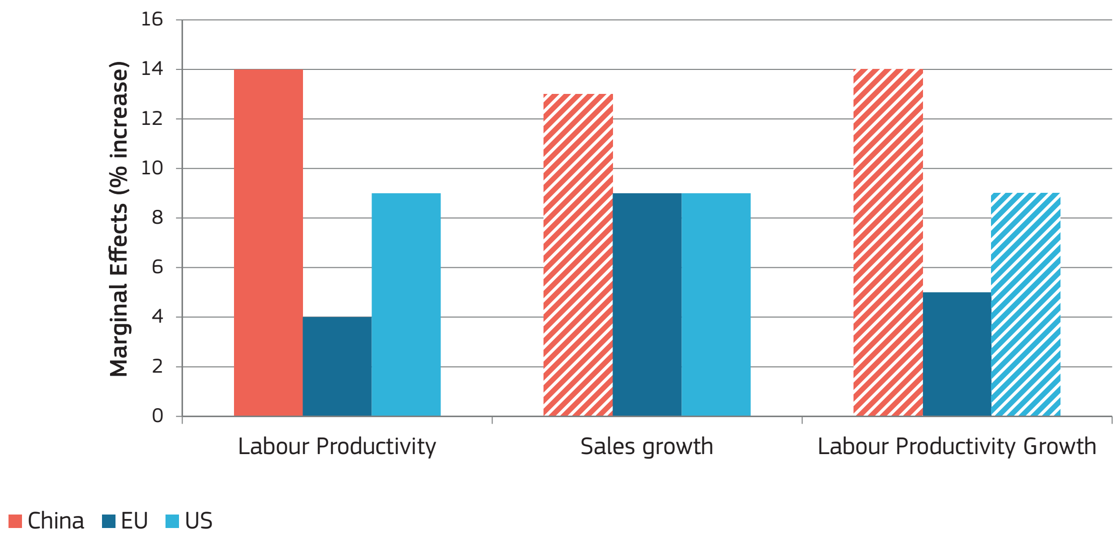


Figure 4.7: M&A and firm performance
Source: JRC calculations based on Bureau van Dijk data (Zephyr and Orbis)

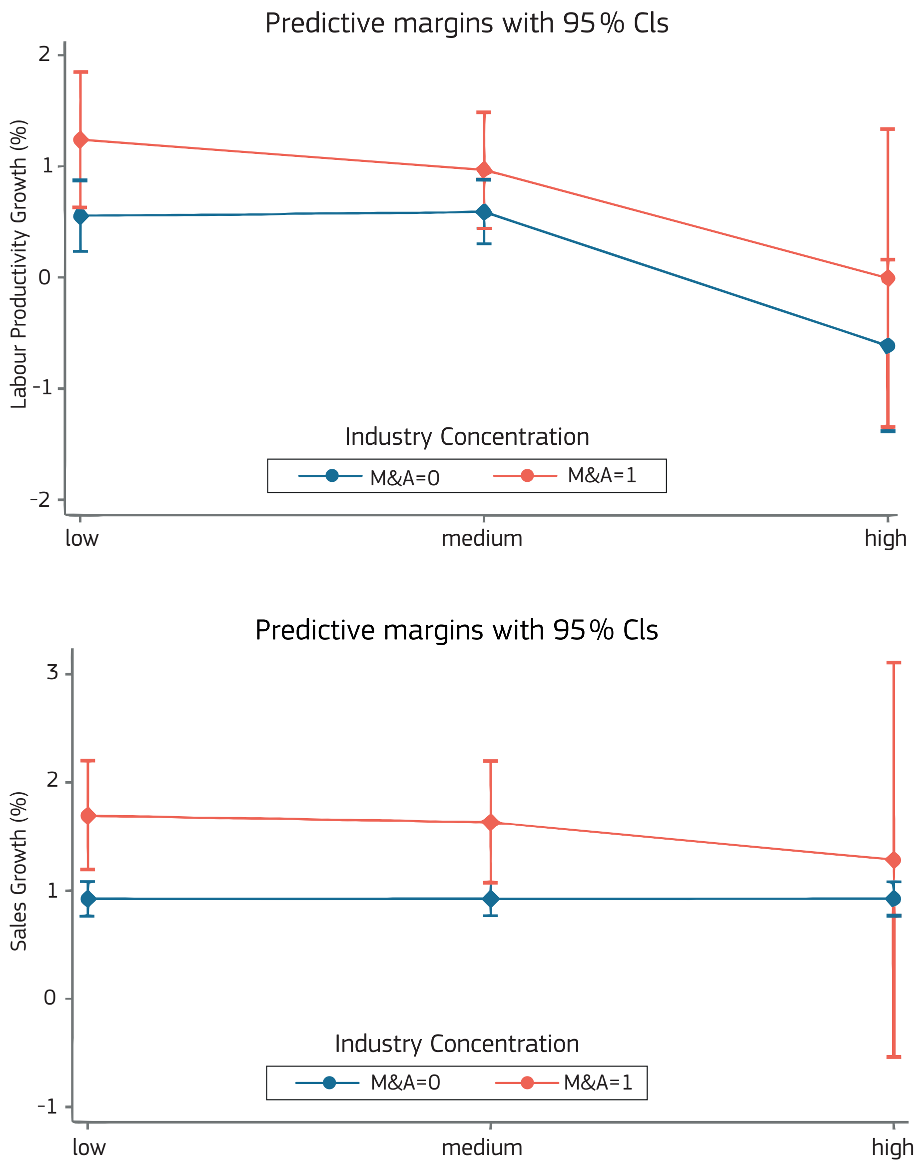


Figure 4.8: M&A, industry concentration and firm performance
Source: JRC calculations based on Bureau van Dijk data (Zephyr and Orbis)


STARTUP

EU-CHINA VENTURE CAPITAL FLOWS ARE MINOR

COMPARED TO THOSE BETWEEN THE US AND CHINA

5.1. China progressively increased its world share of venture capital over the last 7 years

Although the US is still the world's innovation leader, China's technological capability has grown substantially and more rapidly than that of the US in recent years, partly because of the mobilisation of substantial amounts of venture capital (VC) (Deutch 2018; Nepelski et al., 2014). Over the last 7 years, the US has had access to greater amounts of venture capital than the EU or China.

China has progressively increased its share of venture capital, whereas Europe has not caught up with the US.

China's venture capital investments in the EU in 2017 focused on four key technologies closely aligned with Made in China 2025 priorities

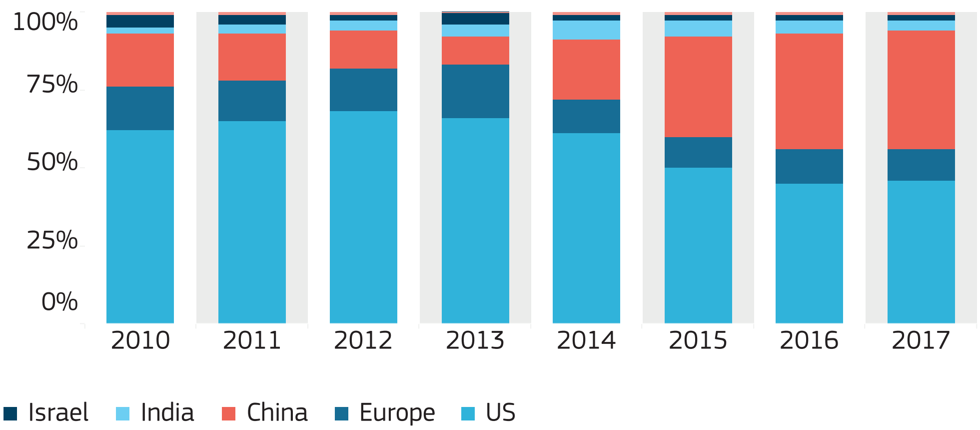


Figure 5.1: World VC trends, 2010-2017
Source: Nepelski et al. (2014)

After a decline in 2012 and 2013, the share of venture capital invested in China grew from 2014 onwards, to reach 38 % in 2017. The share of venture capital invested in the US has declined in recent years from 68 % in 2012 to 46 % in 2017, whereas the share of venture capital invested in the EU has stagnated at around 10-11 % *(Figure 5.1)*[12].

5.2. China's venture capital investment in the US in 2017 was 10 times larger than in the EU

In 2017, the amount of Chinese venture capital invested in the US was EUR 7 billion, whereas the amount going to the EU was much smaller at EUR 685 million *(Figure 5.2)*. The difference between these flows was even higher in preceding years, with a peak in 2015.

The average size of deals between 2006 and 2017 was relatively modest: EUR 18 million in the EU and EUR 36 million in the US. Analysis of Chinese venture capital investments in the US and the EU, by stages of development, shows that China's venture capital firms have significantly increased their interest in US companies over time, especially for seed stage and later stage companies, whereas China has a bias towards financing start-ups in Europe. In 2017, the main geographical destinations for China's VC funds in the EU were Austria, followed by Germany, the UK and Finland, whereas the main geographical destinations in the US were Maine, Pennsylvania, Massachusetts and Maryland.

In terms of China's VC investments in new ventures in the EU and US disaggregated by sectors[13], *Figure 5.3* shows that China's VC funds invested in the EU in 2017 focused on four key technologies closely aligned with MIC 2025 priorities: new materials, energy, healthcare, and IT. In the same year, China's VC investments in the US focused on new materials, healthcare, and IT. In 2017 Chinese investments in the EU in the four MIC 2025 sectors were concentrated in a small number of large firms. By contrast, in the US they are spread over a large number of companies.

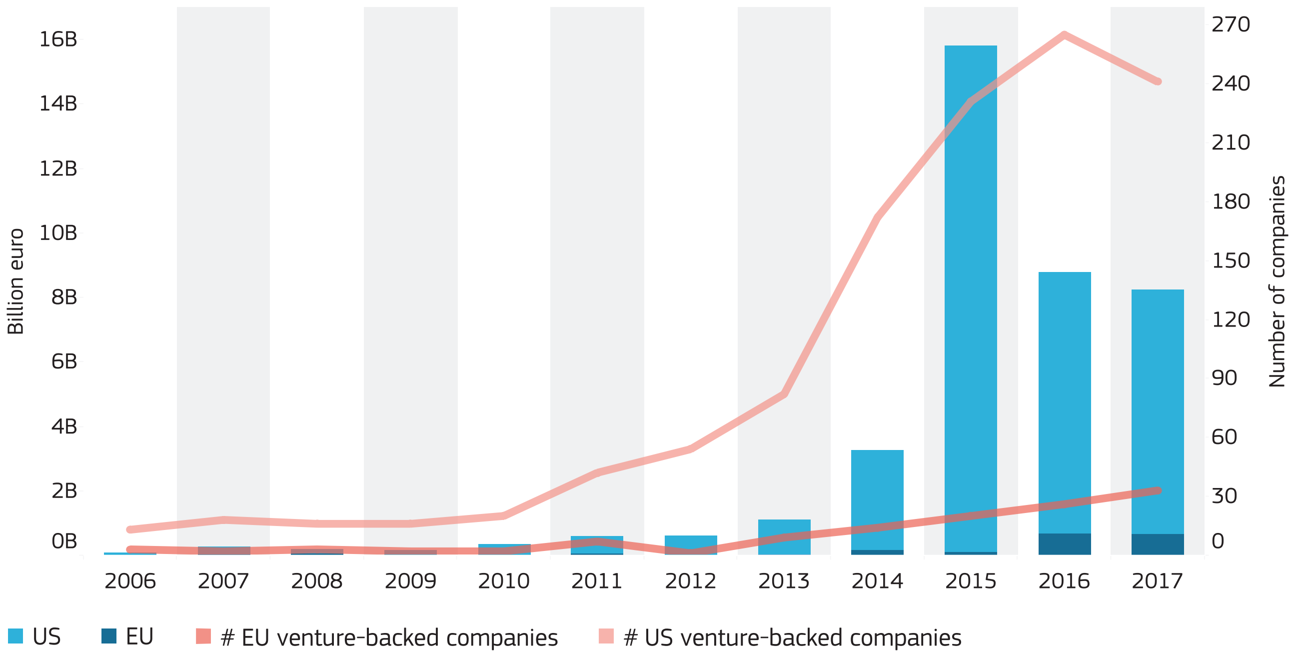


Figure 5.2: China's VC investments in the EU and US by amount and number of companies
Source: JRC computations based on Venture Source data

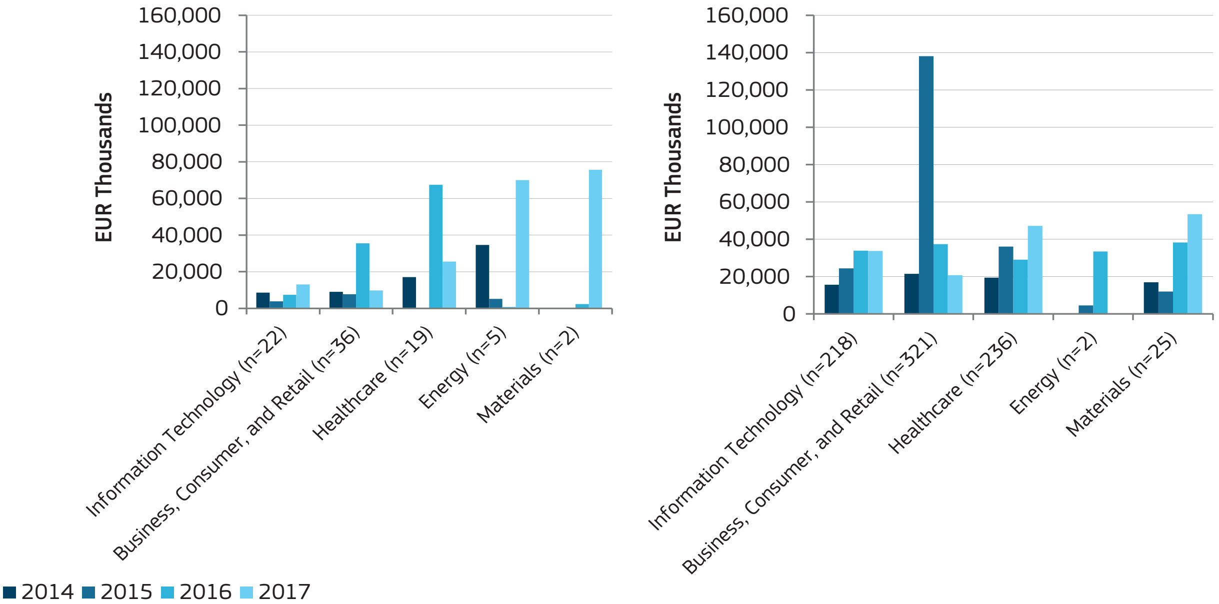


Figure 5.3: China's average VC investment towards EU (left) and US (right) companies, by sector
Source: JRC computations based on Venture Source data

5.3. EU venture capital firms are not taking opportunities to invest in China

Figure 5.4 summarises EU and US venture capital investments in China. Compared to the US, these negligible (the ratio of EU to US venture capital was 7.7 % in 2014, 16 % in 2015, 17 % in 2016 and 3.8 % in 2017). VC investments increased especially after 2014. EU investments dropped again in 2017. Compared to the EU, the scale of US VC investment in China has risen sharply over the last 4 years. For instance, US VC investment in 2017 was EUR 42 billion, compared to only EUR 1.6 billion for the EU. Much of this investment may bring further economic benefits to the Chinese economy.

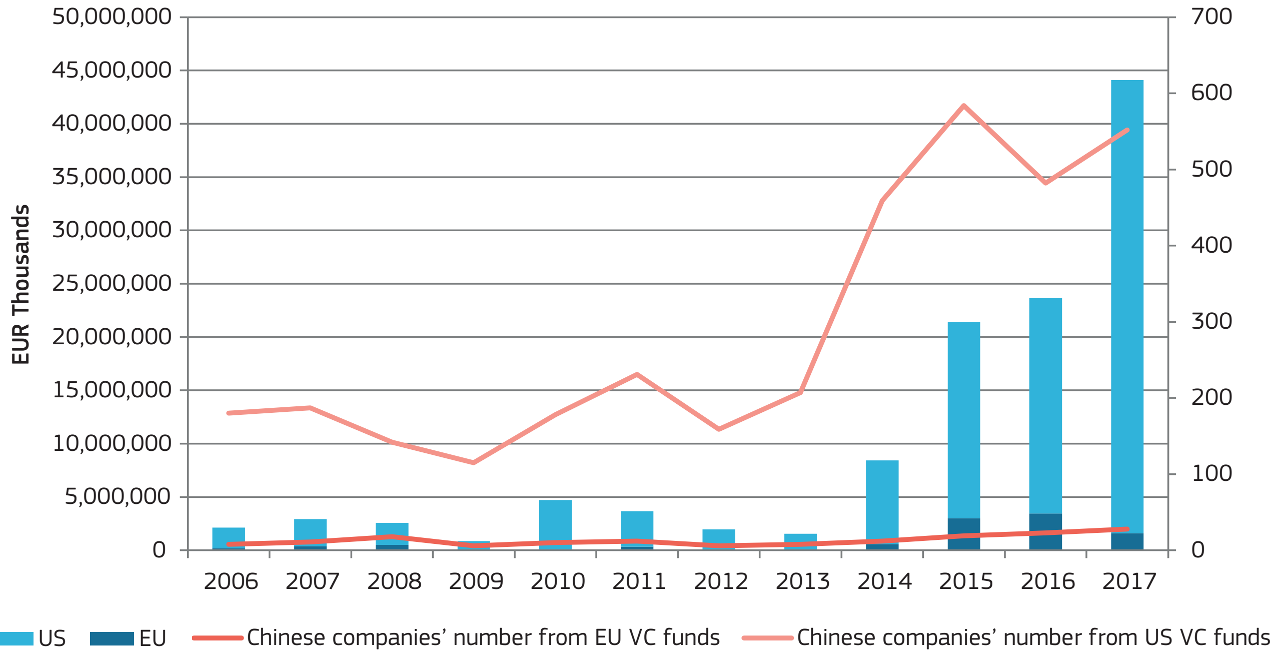


Figure 5.4: EU and US VC investments in China by amount and number of companies
Source: JRC computations based on Venture Source data


BANK

CHINESE BANKS ARE FINANCING EUROPEAN FIRMS

PARTICULARLY THOSE ACQUIRED BY CHINESE FIRMS

6.1. China's financial sector has become the largest in the world

The upsurge in China's real economy has been followed by an equally rapid growth in China's financial sector, now the largest in the world (VoxEU, 2018), with financial assets reaching 470 % of Chinese GDP (IMF, 2017). The world's top four banks are Chinese, with total assets worth 3.7 times the German GDP in 2017 (USD 3.67 trillion) and a growth in total assets of 67 % since 2011. In fact, China's banking sector has doubled in size over the last 7 years.

Chinese banks are supporting the expansion of Chinese companies in the US and the EU

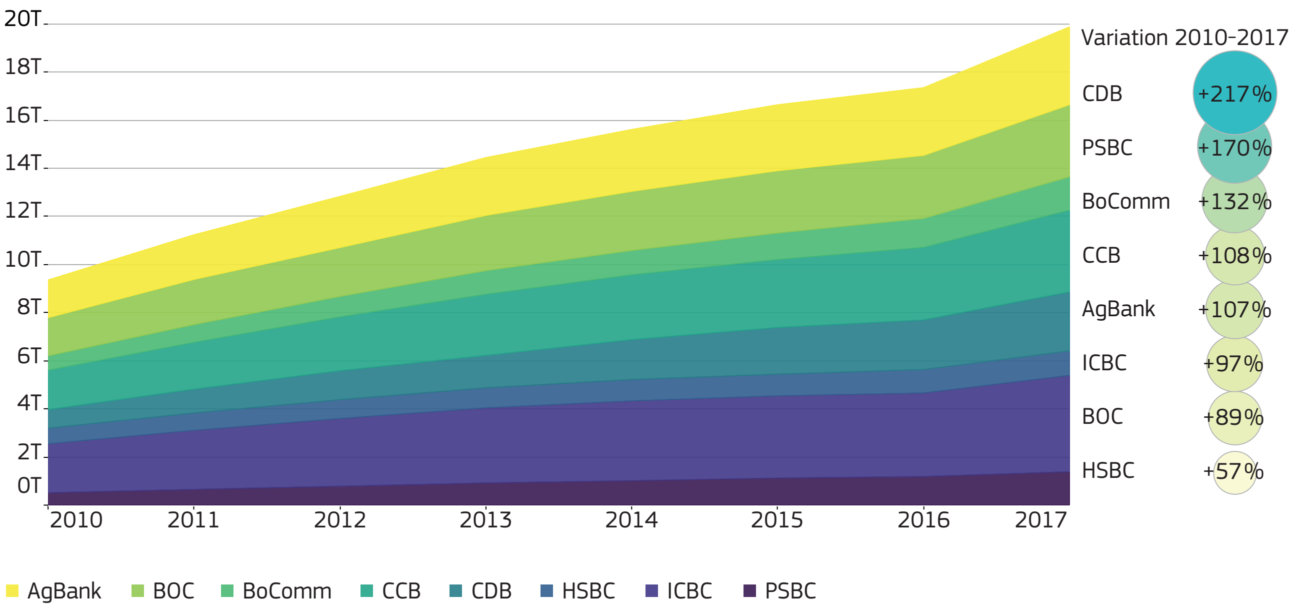


Figure 6.1: Evolution of total assets for the largest Chinese banking groups
Source: JRC elaboration on SNL financial database, data in US$ trillion

Figure 6.1[14] shows growth in total assets for the top seven banking groups located in China and representing 57 % of the total Chinese banking system in 2017.

Although around 70-90 % of the loans and deposits are domestic, participation by Chinese banks in the international loans and deposits market is increasing at an even faster pace than their size. This reflects the pressing need for Chinese banks to diversify their balance sheets, given their fully utilised credit lines at home.[15] SRISK, which measures systemic risk in terms of the expected amount of capital that a financial system should obtain from the world market in the event of a severe financial shock, puts China in first place in 2018 *(Figure 6.2)*, with a risk six times larger than the US and double that of Europe (Engle & Ruan, 2018). By mid-2018, cumulative SRISK for the main Chinese banks had increased by 166 %, compared to 2010. Conversely, it decreased for UK banks by 57 % and for EU banks by 33 % (mainly due to more severe capital requirements to protect investors). The large and rapidly expanding Chinese banking system is also vulnerable to shocks generated elsewhere, acting as a sounding board and further affecting EU markets. This also raises concerns about the potential effects on the global financial markets. In addition, China's debt has increased rapidly and, as a share of GDP, is now approaching that of the countries with the highest in the world *(Figure 6.3)*.

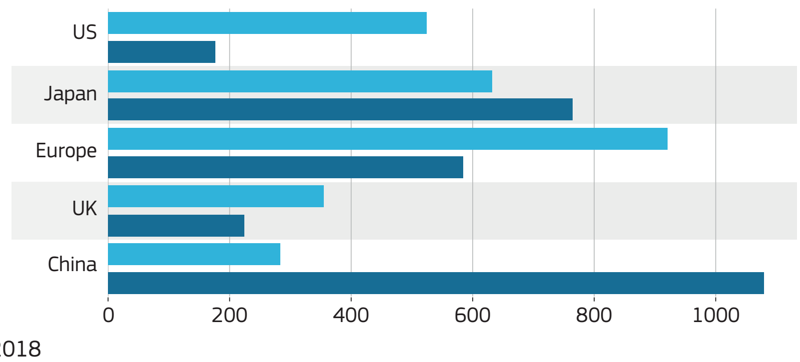


Figure 6.2: Global Systemic Risk by Country
Source: New York Stern V-lab and JRC calculations. Note: The graphs show the SRISK for the top five countries, aggregated across different geographical areas. For Europe, the countries included are France, Italy, Germany and Spain. The UK is indicated separately for the specificities of its banking sector.

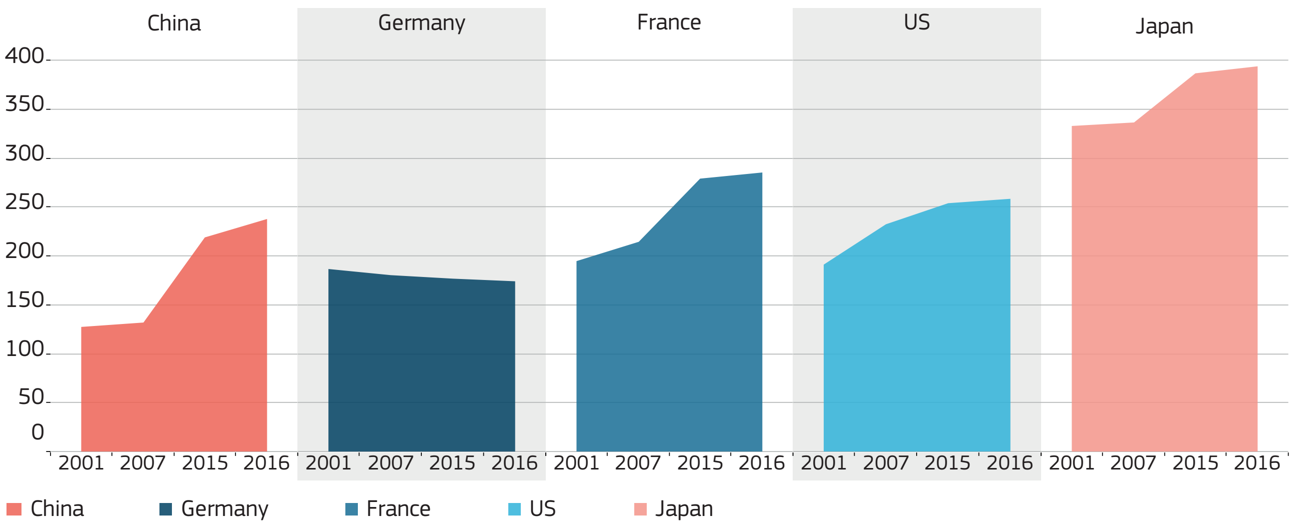


Figure 6.3: Total debt (public + private in % of Gross Domestic Product)
Source: IMF - Global Debt Database

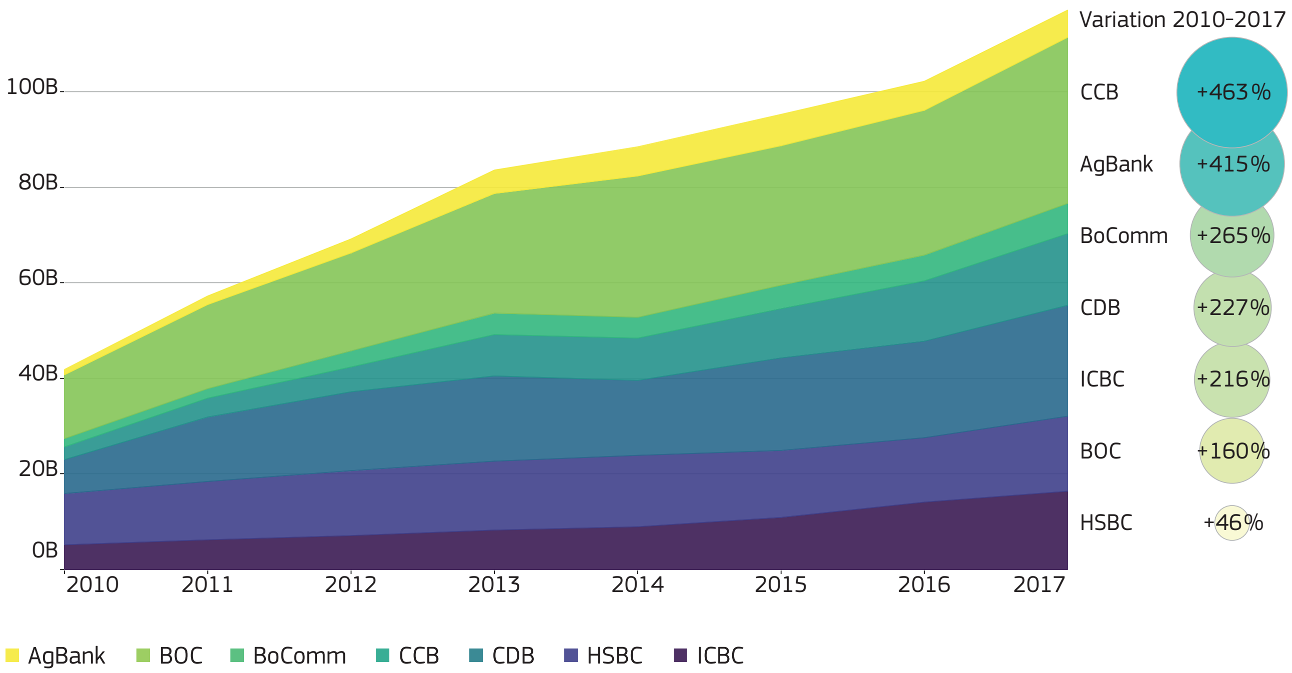


Figure 6.4: Non-domestic loans for the Chinese largest banking groups
Source: JRC elaboration on SNL financial database, data in US$ billion. The groups are: Industrial and Commercial Bank of China Ltd. (ICBC), China Construction Bank Corporation (CCB), Agricultural Bank of China Ltd. (AgBank), Bank of China Ltd. (BOC), China Development Bank (CDB), Bank of Communications Co., Ltd. (BoComm), Postal Savings Bank of China Co., Ltd. (PSBC). Share of non-domestic loans is not available for CDB (years 2016 and 2017) or for PSBC. The variation is computed as total assets in 2017 over those in 2010, minus one.

Figure 6.4 shows Chinese non-domestic loans to all foreign countries[16]. For each banking group, the share remains relatively low (under 10 %), except for Bank of China (21 %) and China Development Bank (14 % in 2015 latest data). The non-domestic loans claimed by these Chinese banking groups show an increase of more than 200 %, highlighting the fact that they are becoming more and more active in international banking. In particular, China Construction Bank Corporation and Agricultural Bank of China increased their foreign loans by more than 400 % in just 7 years.

6.2. China is progressively lending more to the EU, with a 33 % increase in banking claims from 2010 to 2017

Between 2010 and 2017, total investment by foreign investors in loans and deposits to the EU decreased by 22 %;[17] more specifically, there was a consistent decrease between 2010 and 2015, followed by an inverted trend from 2016 *(Figure 6.5)*.

However, Chinese banks have increased their presence in Europe since 2012. China's cross-border banking claims in the EU amounted to USD 279 billion in 2017, up from USD 210 billion in 2010. Chinese claims on loans and deposits represent 7 % of EU banking groups' claims from non-EU investors *(Figure 6.6)*. Note that 11 % of foreign claims come from banks resident in offshore financial centres (OFCs). In particular, financial institutions in the Cayman Islands represent 81 % of OFC international banking claims in the EU, followed by the Bahamas with 7 %. The nationalities of investors behind these investment flows are unknown; however, for at least a proportion of them, Chinese origin cannot be ruled out.

The detailed financial position of Chinese banks in Europe can be seen from the perspective of the syndicated loan market[18]. A syndicated loan is a specific type of loan, which involves an offer by a group of lenders to provide joint funds for a single borrower. The borrower could be aiming to finance

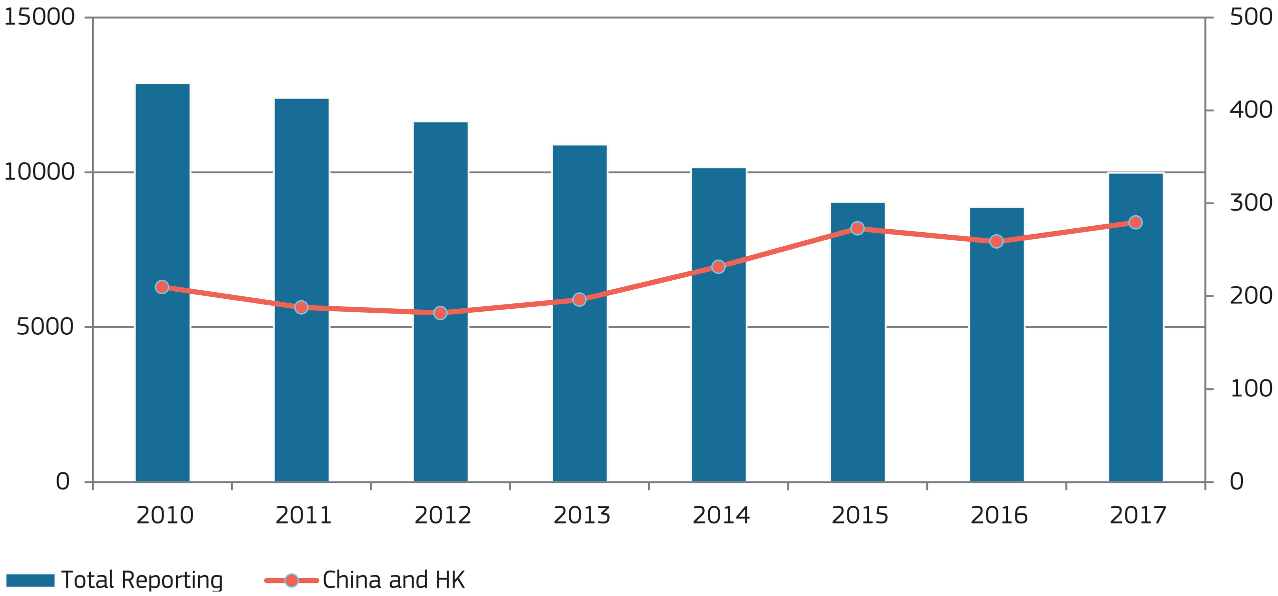


Figure 6.5: Loans and deposits by non-EU investors in Europe, $ billion
Source: JRC-ECFIN Finflows database, JRC computations. The value represents total investment loans and deposits into EU countries reported by foreign banks. Chinese claims are represented on the right axis.

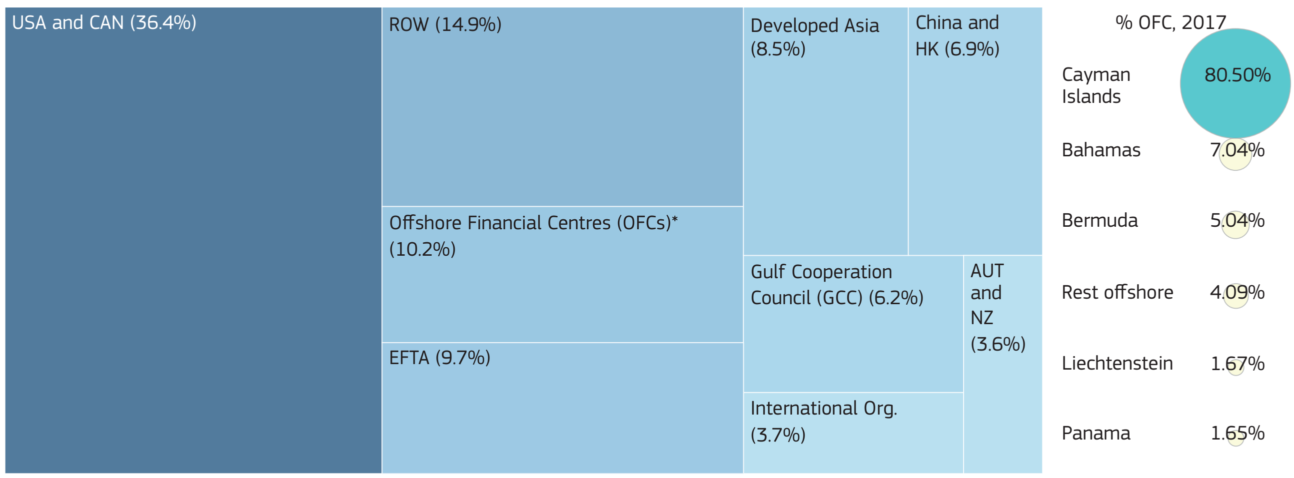


Figure 6.6: Share of non-EU loans and deposits into EU28 in 2017, by origin of investing country
Source: JRC-ECFIN Finflows database, JRC computations. The value corresponds to the total of investment loans and deposits positions claimed into EU countries in 2016 by non-EU banks whose origin is known.

a very large project, such as a major M&A or infrastructure project, or be a sovereign entity such as a government. For example, Chinese Tencent Holdings Ltd., Asia's largest internet company and owner of the messaging services WeChat and QQ, signed a syndicated loan deal on 24 March 2017, to raise USD 4.65 billion.[19]

There has been a sharp increase in the presence of Chinese banks in the global syndicated loan market since 2013, reflecting the increased international presence of Chinese firms under the auspices of the China Going Global strategy. Among the total amount of syndicated loans made by Chinese firms, the largest share is domestic (36 %), followed by deals with borrowers located in Hong Kong (11 %), the US (11 %) and the EU-28 (10.80 %).[20]

The European syndicated loan market was worth USD 430 billion in 2017, with China being the fourth largest foreign lender with USD 19 billion (4.4 %). This share, although far below that of the US and Japan (36 % and 32 % respectively), has grown more than six times in the last 10 years *(Figure 6.7, left panel)*, coming close to that of Switzerland (6 %). This goes hand in hand with the increased investments by Chinese firms in Europe, with a correlation of 0.84 between the value of M&A deals in the period 2007-2017 and the amount of syndicated loans involving Chinese banks.

A more in-depth analysis of the borrowers shows that, among the 50 largest EU borrowers, 10 have some Chinese shareholders and 6 are fully controlled by a Chinese shareholder. According to JRC data, when Chinese owners purchase a European firm, the acquisition is followed by lending. This was the case for the tyre producer Pirelli, which was acquired by the China National Chemical Corporation in November 2015. In 2016 and in 2017, Pirelli obtained two syndicated loans, with Chinese banks playing a major role for the first time. Looking at the nationality of the borrowing firm *(Figure 6.7, right panel)*, the UK stands out as the main recipient of syndicated loans involving Chinese banks, with a share of 26 %. About 50 % of the syndicated loan market is made up of borrowers located in France, Germany, the Netherlands, Luxembourg and Italy.

The flow of money from China to Europe is, in principle, positive and provides an alternative source of funding for the European economy. However, the increasing level of non-performing loans on banks' balance sheets and the strong government influence on the financial sector could make the Chinese financial system a source of risk to global financial stability. Furthermore, the demand for high-yield investment products, coupled with increased oversight of the Chinese banking sector, has moved risky lending away from banks and towards less supervised parts of the financial system, bringing additional threats to Chinese (and global) financial stability and hence to economic growth at large.

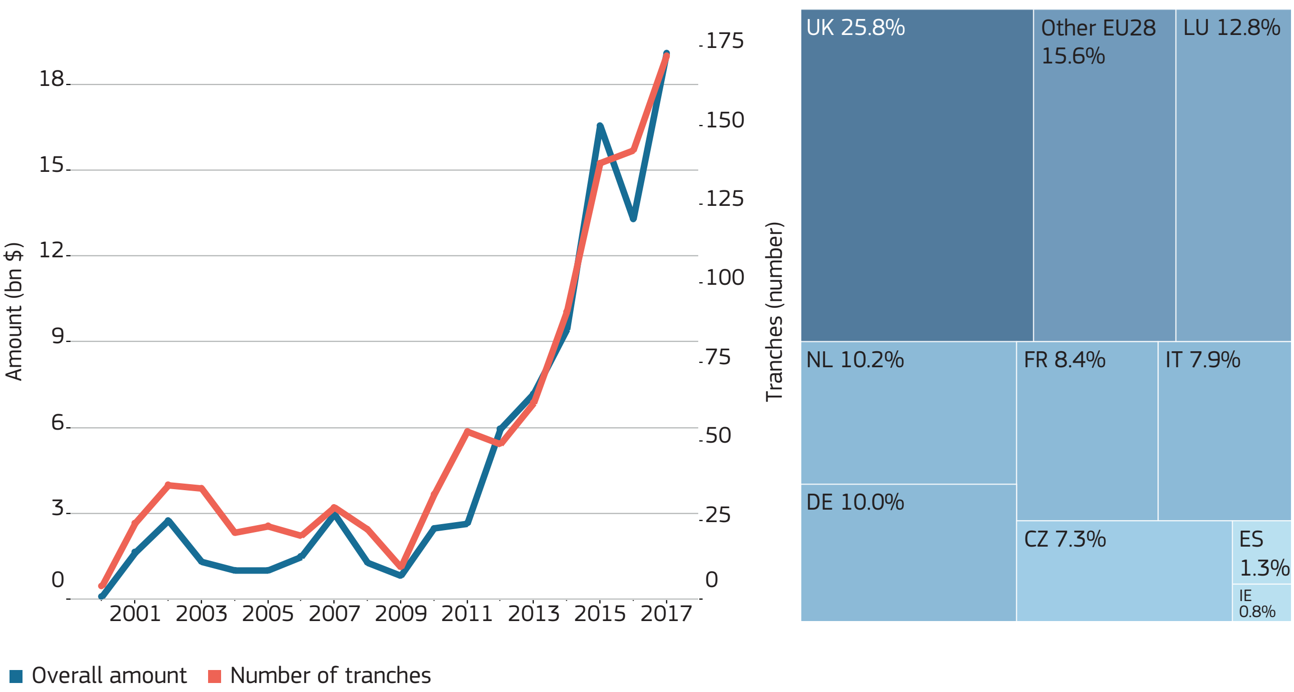


Figure 6.7: Syndicated loans involving Chinese banks
Source: JRC elaboration on LoanConnector. Note: The graphs show the total amount lent by Chinese banks (blue line) and the numbers of deals in which at least one Chinese bank was part of the syndicate (red line). On the right panel, the sample is restricted to borrowers located in the EU28. The amount lent is in US dollars (billion); period 2000-2018 (May).

EU INVESTMENTS IN CHINA SUFFER FROM RECIPROCITY CONCERNS

7.1. Chinese acquisitions in the EU are double those made by EU investors in China

While Chinese presence in Europe is increasing rapidly *(Chapter 4)*, European penetration of the Chinese market is much slower. In the period 2010-2018q2, there were over 400 M&As by China in the EU, but 35 % fewer by the EU in China (around 270). There were over 500 deals (M&As and minority) by Hong Kong in the EU, but less than 150 by the EU in Hong Kong. China is almost five times more restricted than the OECD average in terms of inward FDI *(Chapter 8)*. Moreover, China treats foreign firms differently to domestic firms. In the Chinese service sector, for example, there is heavy protection from, if not legal prohibition of, foreign investments in sectors like IT services, data centres, software development and media. In other sectors, typically manufacturing, foreign investment is legally possible but unlikely, e.g. in semiconductors, automation and robotics, and utilities. Overall, MERICS estimates that three out of four of the largest Chinese acquisitions in Europe since 2000 could not have happened the other way around (MERICS, 2018).

> Access of EU companies to the Chinese market is difficult and they are also subject to unequal treatment post-entry

Once a European company enters the Chinese market, it is also subject to unequal treatment post entry, for instance, China imposes mandatory contract terms that discriminate against and are less favourable for foreign IPR holders (ECC, 2018b; EC, 2018b). What is more, about half the 532 respondents to a European Chamber of Commerce in China survey among EU firms in China believe that regulatory barriers will increase over the next 5 years, in spite of legal openness announced by the central government *(Chapter 8)*.

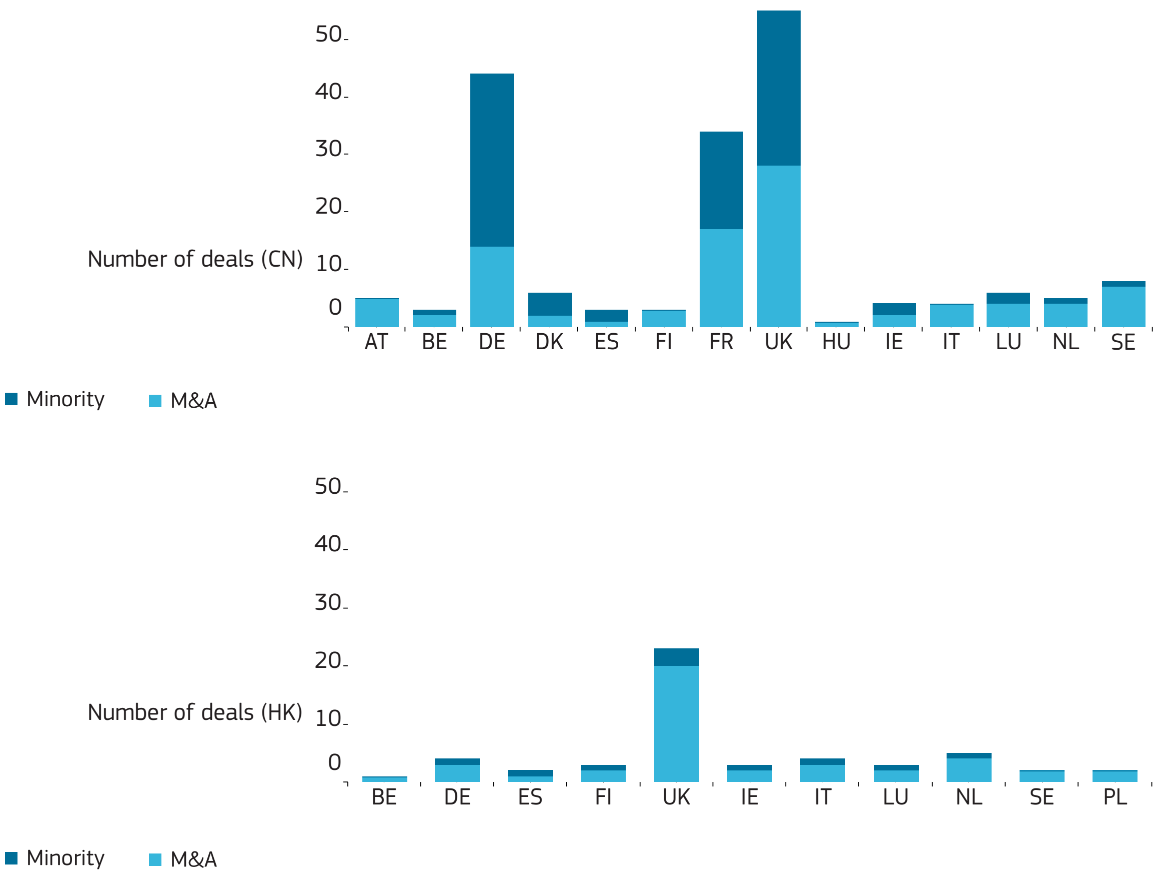


Figure 7.1: Number of European deals in China (1st panel) and Hong Kong (2nd panel) by nationality of the investor, 2015-2018q2
Source: JRC computations on foreign ownership database. The figures report the number of deals in China, by country of the investor, separating M&A and minority investments

7.2. EU firms enter China through joint ventures and investment in minority stakes rather than through mergers and acquisitions

The discrimination in favour of Chinese firms has favoured foreign-Chinese joint ventures and foreign investment in minority stakes. Over the period 2015-2018q2, the top three European investors in China (for number of deals) were the UK, followed by Germany (where minority deals were more than double M&As) and France *(Figure 7.1, first panel)*. The tendency to invest in minority stakes, which do not result in control over the target company, does not extend to EU deals in Hong Kong *(Figure 7.1, second panel)*. This is probably due to the market openness and different regulatory environment in this financial hub. Manufacturing and ICT are the two leading sectors for EU investment in China, accounting for almost 80 % of the 180 European deals in China over the period 2015-2018q2 *(Figure 7.2)*. Finally, about 30 % of all European deals in China relate to manufacturing sectors included in the Made in China 2025 strategy (MIC 2025). *Figure 7.3* details the distribution of these deals across sectors.

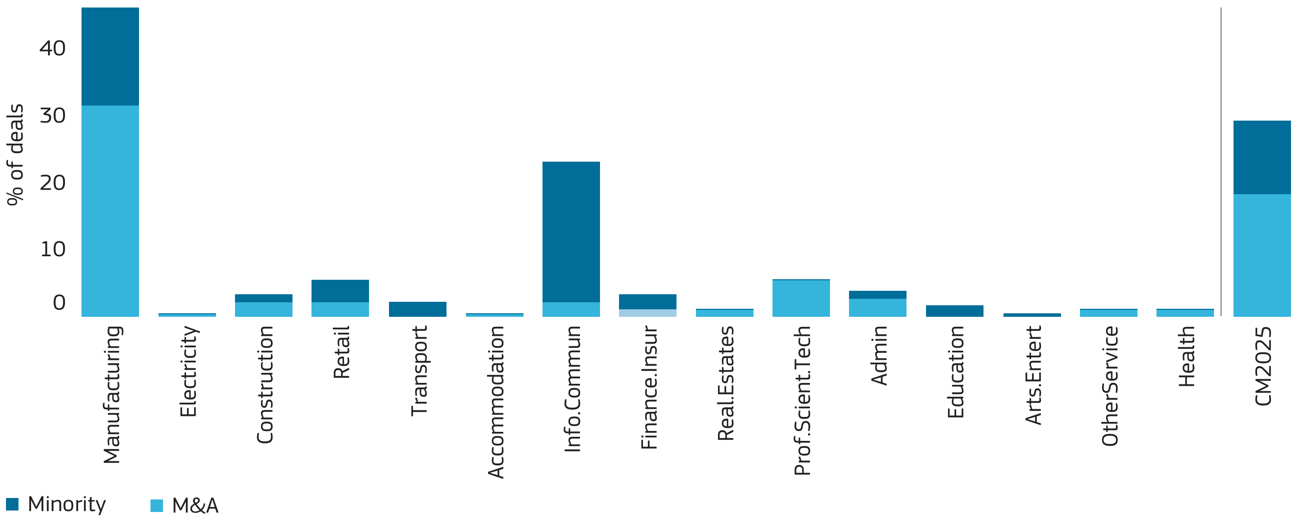


Figure 7.2: Percentage of European deals in China (M&As and minority stakes), by sector of the target investment, 2015-2018q2
Source: JRC computations on foreign ownership database. The last column of the figure reports the percentage of the deals in sectors involved in the China Manufacturing 2025 strategy (CM2025)

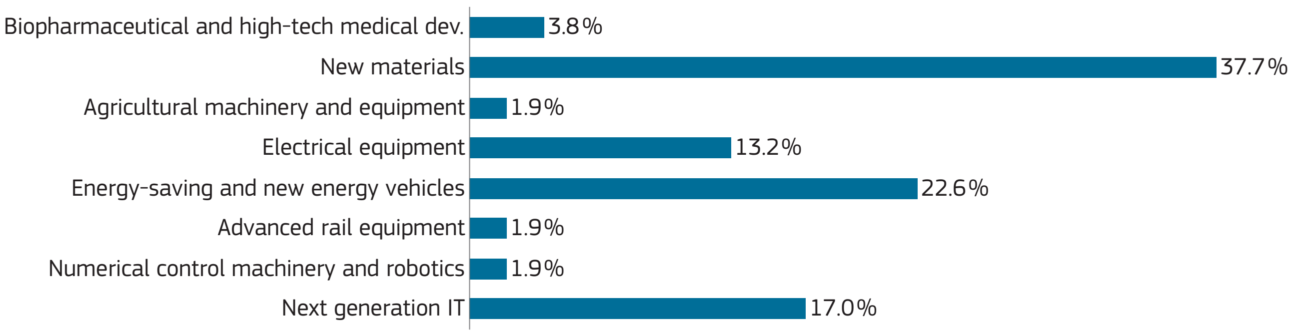


Figure 7.3: Percentage of European deals (M&As and minority stakes) related to MIC 2025. Data ordered by sector of the target investment, 2015-2018q2
Source: JRC computations on foreign ownership database

CHINA: AN UNEVEN PLAYING FIELD FOR EUROPEAN COMPANIES

8.1. China announces further opening up of its domestic market and improvement of business framework conditions

The regulatory framework in China is of longstanding concern, and affects the overall business environment and Foreign Direct Investment (FDI). There is frequent criticism of the formal and informal discrimination towards private firms and the unequal treatment of domestic and foreign firms. In the past few years, the Chinese government has initiated a number of reforms and changes to the system, emphasising market forces and a liberalisation of several regulations. President Xi announced the further opening up of China's domestic market and overall improvement of business framework conditions[21] in his speech at the 2017 World Economic Forum in Davos (WEF, 2017). The main cornerstones of this intervention were further developed in official documents (State Council, 2017a and 2017b). While there was general satisfaction with the proposals, several commentators and businesses criticised the lack of concrete actions following these plans (ECC, 2018b; MERICS, 2018). European actors continue to stress the need for reciprocity and a level playing field in their negotiations with the Chinese government.

Challenges include regulations and limitations on market access, insufficient IPR protection, unfair and unequal treatment

At the EU-China Summit in 2018, government representatives from both sides agreed on a joint statement for the first time since 2015 (EC, 2018a). The EU acknowledges the efforts made by China, but tensions still remain. WTO legal proceedings were started against Chinese legislation undermining the Intellectual Property Rights (IPR) of European firms (EC, 2018b). This issue was also taken up by the European Parliament (EP, 2018). American counterparts are also working on an adequate response to Chinese policies (Deutch, 2018). Some progress has been made, but an unequal playing field remains a challenge to EU-China relations.

8.2. China offers less favourable foreign direct investment conditions than the EU

China's restrictions on FDI are much stronger than in the EU *(Figure 8.1)*. In some sectors, including car manufacturing, companies are forced to engage in joint ventures with Chinese partners. In others, e.g. financial services, foreign investors can only become minority shareholders or are not allowed to invest at all *(Chapter 7)*. The approach to IPR protection may confer an unfair advantage on Chinese firms. In some cases, foreign firms cooperating with a Chinese partner must disclose their IP, which can be used in exchange for various privileges on the local market (Jungbluth, and Laudien, 2016; Gros, 2018).

8.3. Deterioration in framework conditions for business

Business surveys published by the European Chamber of Commerce in China in 2017 and 2018 and the German Chamber of Commerce (AHK, 2017) emphasise the challenges and obstacles remaining for foreign companies in China. These challenges include regulations and limitations on market access, insufficient IPR protection, unfair and unequal treatment, as well as quasi-monopolies of state-owned enterprises (SOEs) with government support, and discrimination against foreign companies in public procurement procedures. Ambiguous rules and regulations still represent a major problem for 48 % of the European firms operating in China – a share which has remained stable over the past few years. Representatives of US government agencies and companies have raised similar concerns (USTR, 2017; Atkinson, 2018). American firms also face challenges such as IP cyber theft and illegal technology transfer, market access restrictions, mandatory transfer of technologies and unequal treatment (Deutch, 2018; AmChamChina, 2018).

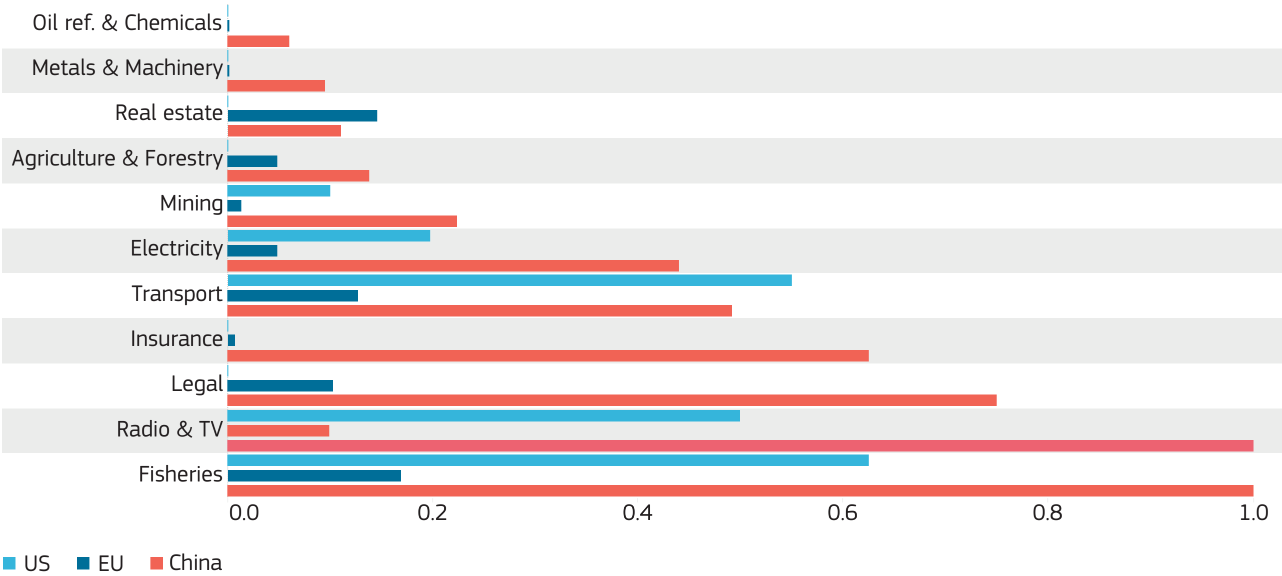


Figure 8.1: Chinese restrictions on FDI are higher than in the EU in every single sector except real estate
Source: FDI Restrictiveness Index – OECD, 2017

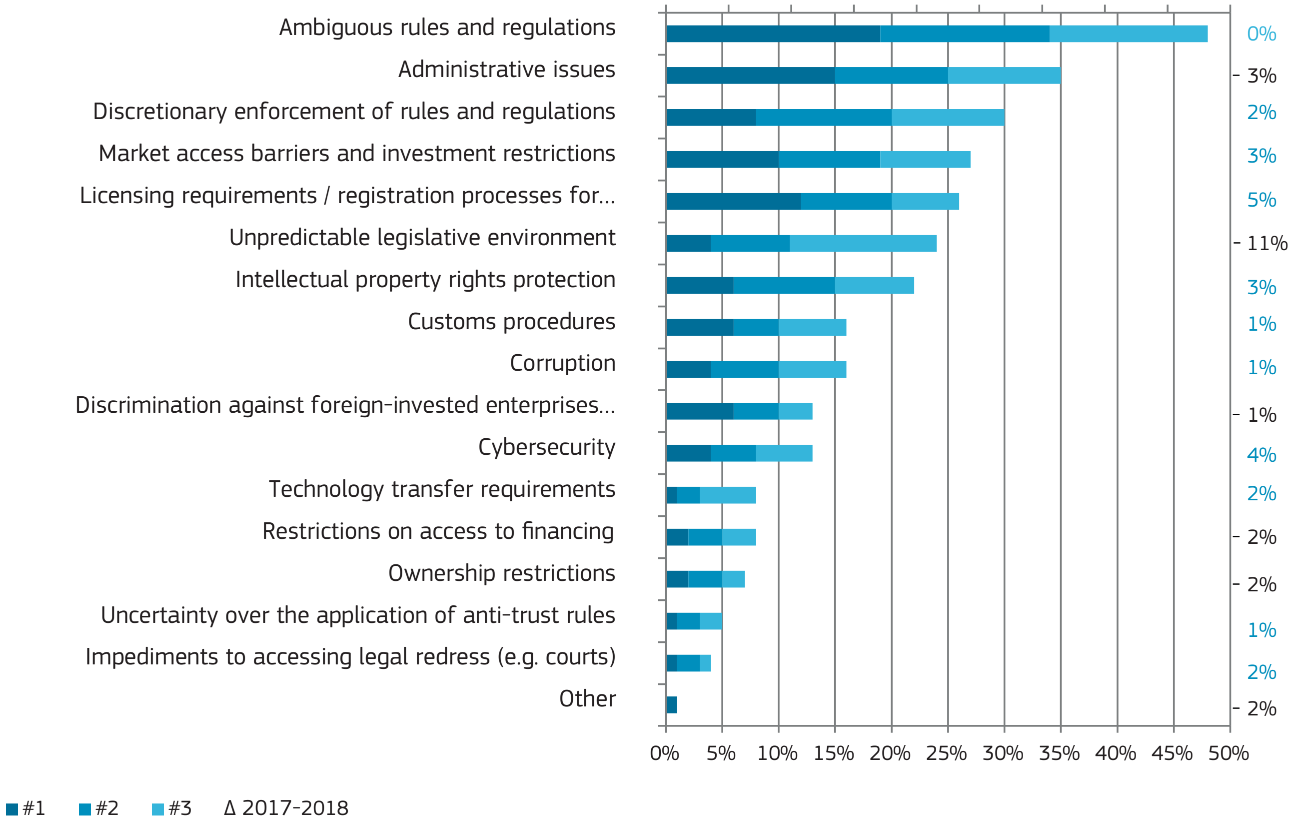


Figure 8.2: Top regulatory obstacles
Source: European Chamber of Commerce in China, 2018

8.4. EU small and medium enterprises, ICT, legal and pharmaceutical companies report unequal treatment

The perception persists that local firms are treated more favourably compared to European ones *(Figure 8.3)*. Especially prevalent among the issues raised by survey respondents are unequal treatment of European firms on administrative issues and market access.

A particularly high share (>70 %) of EU companies in the legal, pharmaceutical and IT sectors report unequal treatment *(Figure 8.3)*. Respondents from firms operating in the pharma and medical devices sectors also express financial pessimism *'largely due to unofficial support for the procurement of local devices and drugs'* (*Figure 8.3)*. Small and Medium Enterprises (SMEs) are more likely to suffer from unequal treatment because of their size, which means they lack the instruments to influence their ecosystem. They cannot participate in the shaping of legislation and programmes and have less clout to influence government actors. They indicate that this unequal treatment affects their potential for scaling up and profitability (ECC, 2018b).

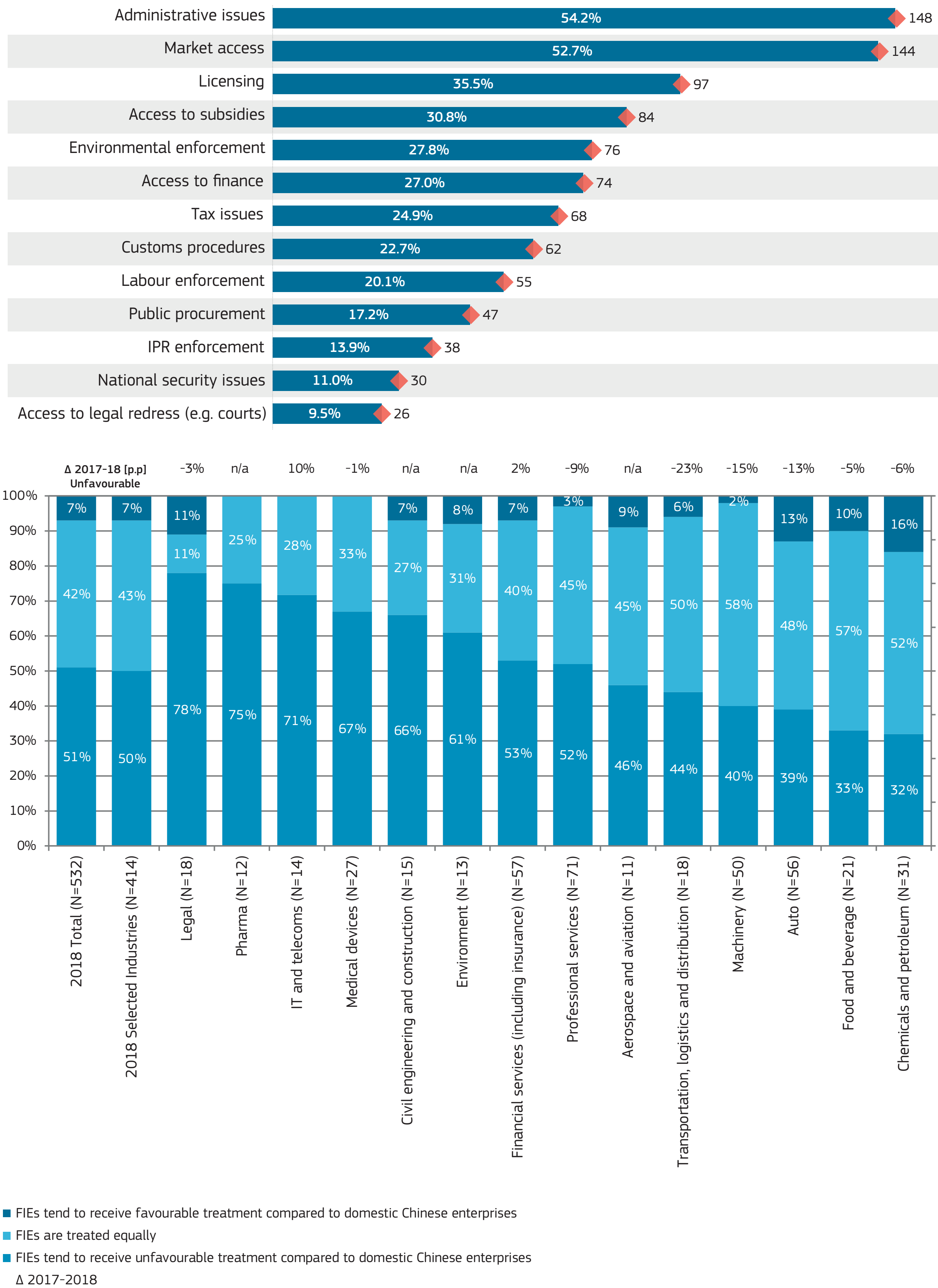


Figure 8.3: Breakdown of unfavourable treatment (top: per area; bottom: per industry)

Source: European Chamber of Commerce in China, 2018

8.5. Chinese high-tech companies are becoming very competitive

For a very long time, foreign countries have looked to China for fruitful business opportunities based on higher technological and innovative capabilities, while the competition from Chinese companies was limited and mostly restricted to low-end market segments or low-tech sectors (Prud'Homme and von Zedtwitz, 2018; Liu et al., 2017).

At present, the competitiveness and innovativeness of Chinese companies matches those of foreign companies in many areas and sectors (ECC, 2018a; AmChamChina, 2018), a phenomenon mainly driven by domestic demand for high-quality goods and services. In 2018, for the first time the majority of Europeans (61 %) consider their Chinese counterparts to be equally or even more innovative than them. This is mainly true for domestic firms' capability for product/service innovation, rather than their capacity for 'go-to-market' and business model innovation (ECC, 2018b).

8.6. Improvements in intellectual property rights, joint ventures and environment, alongside tough domestic competition for foreign companies

Although the implementation of the proposed reforms (State Council, 2017a; 2017b) is advancing more slowly than expected, progress has been reported in several fields. In the area of Intellectual Property Rights (IPR), due to the international expansion of Chinese firms, the government took decisions that provide more effective protection. IP courts and tribunals have been established across the country. This has also had a positive effect on European firms operating in China. It has to be noted though that many international companies still suffer considerable damage from IPR infringement (ECC, 2018b; CommIP, 2017). In the area of R&D, efforts are also bearing fruit, with certain sectors' joint ventures already eligible for funding (ECC, 2018a). In the area of environment and environmental enforcement, European companies report that rules are gradually being applied more evenly to domestic and foreign firms. There is still room for improvement in this area though, especially when it comes to state-owned enterprises.

However, despite good financial results, 46 % of respondents plan to cut costs in China in 2018. This is 'driven in part by a more subdued outlook on future profitability, which is a result of the increasingly difficult business environment and growing competition from domestic firms' (ECC, 2018b). It is worth mentioning that the liberalisation and opening-up policies announced and already started are seen as either too half-hearted or ineffective, while for other policies - like the lifting of certain restrictions on the investment list – results are not yet visible (EC, 2018a). There has been increased competition for foreign companies in China in recent years, both from outsiders and from Chinese competitors, who were able to enter high-tech/high-end markets. As reported in business surveys, the most frequent obstacles for foreign companies in China are ambiguous rules, human resources, access to market, cybersecurity and unequal treatment. While the IPR system is formally similar to Western systems, and the legal authorities have been further professionalising in this field, the issues of enforcing IPR and of forced technology transfers remain among the top obstacles for foreign presence in China.

CHINA HAS BECOME A RESEARCH & INNOVATION POWERHOUSE

9.1. China overtakes the EU in intensity of both Gross Expenditure on research & development and business expenditure on research & development

As discussed in Chapter 1, Research & Innovation (R&I) policy is central to the Made in China 2025 strategy. China recently surpassed the EU-28 in terms of R&D intensity. The dotted line in *Figure 9.1* shows that China was close to its 2.2 % target for the 2011-2015 planning period. Unlike the EU with its Lisbon target, China is expected to achieve its aim to further increase its R&D intensity to the level in its medium- and long-term plan, namely 2.5 % by 2020.

The relatively narrow specialisation for scientific and technological output does not limit China's ability to meet the targets of Made in China 2025

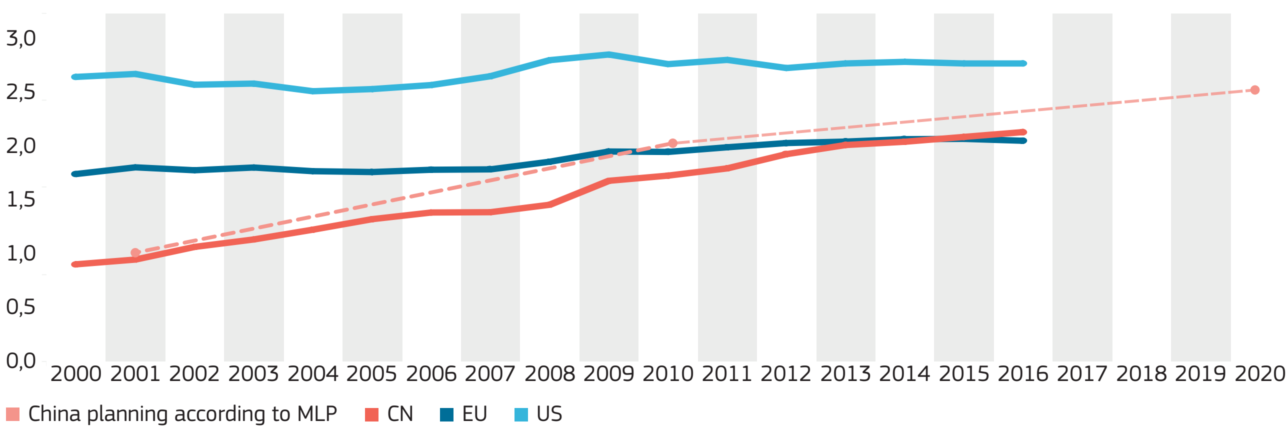


Figure 9.1: GERD intensity in the US, EU and China
Source: OECD – MSTI for China in 2016, United States in 2015 and 2016; Eurostat for the European Union

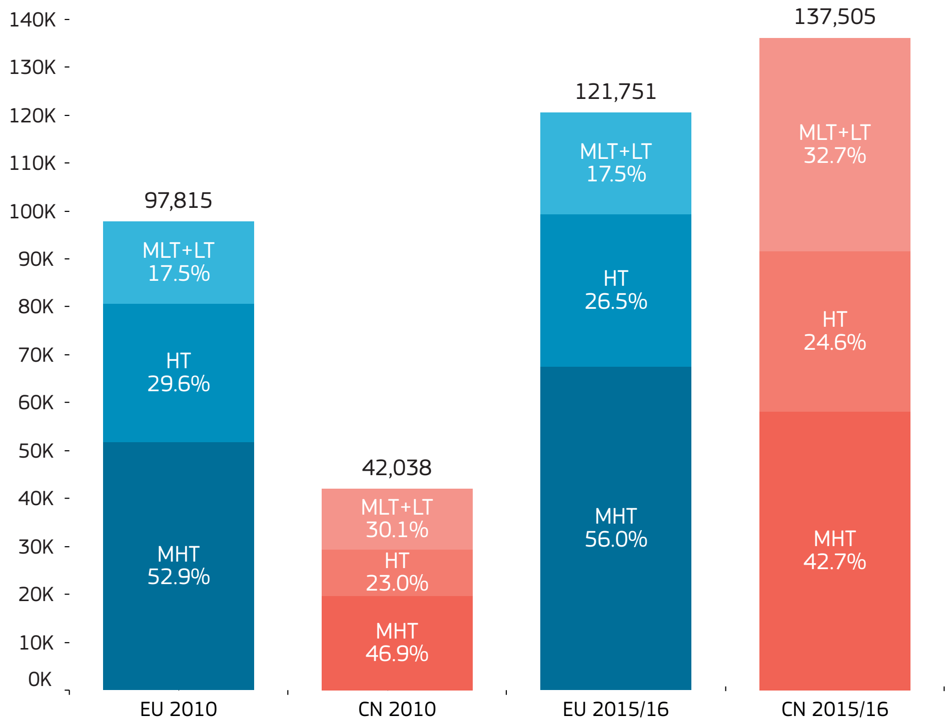


Figure 9.2: BERD in HT/MT/LT sectors in the EU and China
Source: China Statistical Yearbook of S&T 2001; 2017 - Eurostat

A total of 77 % of Gross Expenditure on Research & Development (GERD) is expenditure by businesses. This is similar to Japan and Korea, but this share is lower in the EU and the US (EU: 64 %; US: 71 %). The 2018 edition of the European Innovation Scoreboard indicates that China is catching up, at three times the EU's innovation performance growth rate (EIS, 2018).

According to Chinese government figures,[22] Chinese Businness Expenditure on Research & Development (BERD) has tripled in the last 6 years. It is now higher than BERD in the EU *(Figure 9.2)*. In 2010, there was still a large gap between the EU and China in high-tech (ICT and pharma) and medium-high-tech (including automobiles). By 2015/2016, this gap had been largely closed. The JRC collects data on the world's 2 500 largest private R&D investors: Chinese scoreboard firms show a faster growth in R&D expenditure than scoreboard firms headquartered in the EU, the US or Japan (Scoreboard, 2018).

9.2. Science & technology output has dramatically improved and the output and impact of China's publications and patents are rising fast

The total output from the Chinese science system is rising exponentially and China is close to overtaking the US in high-impact papers *(Figure 9.3)*. The average quality of China's publications is increasing. The share of the top 10 % most cited papers is already above the world average of 10 %. It is, however, still well below the shares of the EU and the US.

China's output of patents targeting international markets (European Patent Organisation (EPO) and Patent Cooperation Treaty)[23] grew at an annual average rate of 22.3 % between 2006 and 2015 *(Figure 9.4)*. It is still behind Japan, the EU and the US, but has already overtaken every single EU country. The computer, electronics and optics sectors account for almost 30 % of all China's transnational patents.

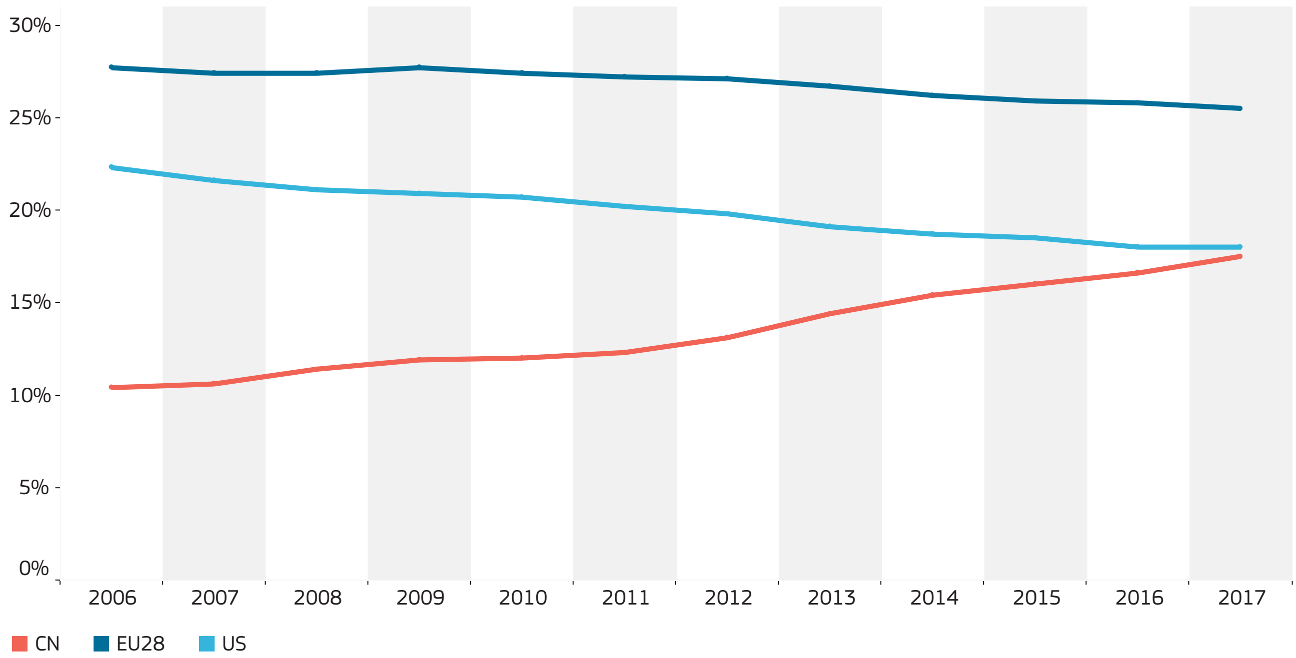


Figure 9.3: Top 10 % highly cited publications - US, EU and China world shares
Source: Elsevier Scopus data

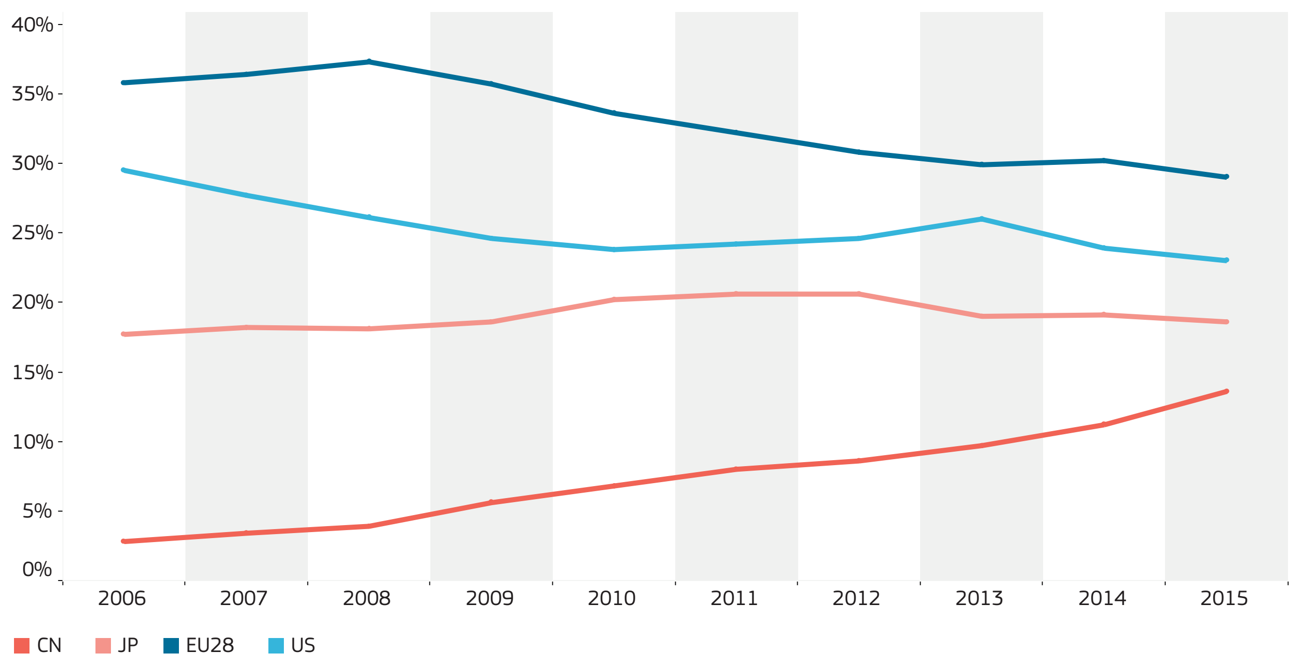


Figure 9.4: World shares in transnational patents filings (EPO+PCT)
Source: PATSTAT - computations based on Frietsch *(forthcoming)*

9.3. Science & technology capabilities must be broadened to meet the Made in China 2025 priorities

The specialisation profile of China's top innovators is narrow, built around a subset of ICT-related technologies, particularly in audiovisual technology, computer technology, semiconductors, optics, telecommunications, digital communication, and micro-structural and nano-technologies. Top corporate R&D investors headquartered in the EU (24 fields of specialisation) and the US (21 fields) show a broader specialisation profile than their Chinese counterparts, with comparative advantages in key technologies to address key societal challenges such as health and the environment *(Figure 9.5)*. Similarly, scientific specialisation in China is focused on the natural sciences, computer science and material science. The US and EU have a more balanced portfolio, with comparative strengths in life sciences and social sciences *(Figure 9.6)*.

Related to this, China has a relatively high share of BERD in chemicals, machinery and equipment, electrical equipment, and computer, electronic

Figure 9.5: Revealed Technological Advantage of Scoreboard firms
Source: JRC elaboration on PATSTAT data

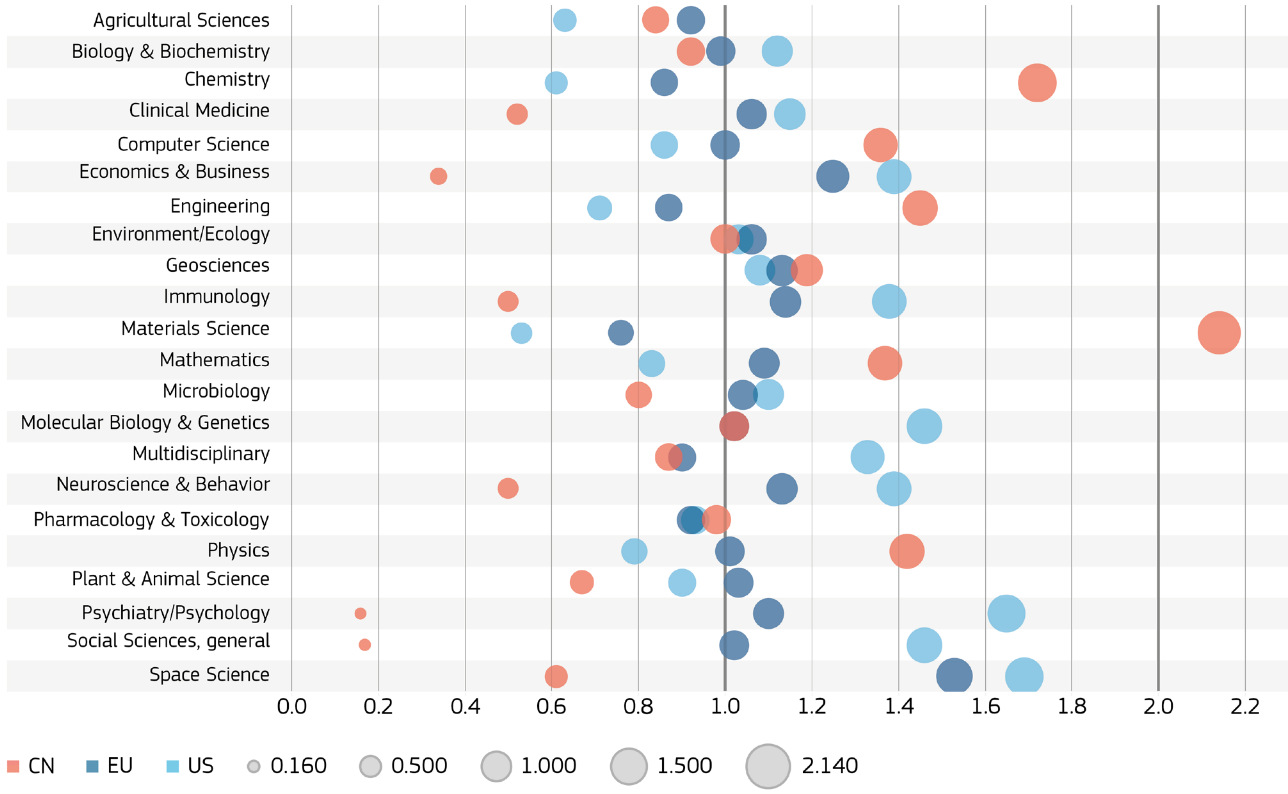


Figure 9.6: Revealed Scientific Advantage Firms
Source: JRC elaboration on Scopus data

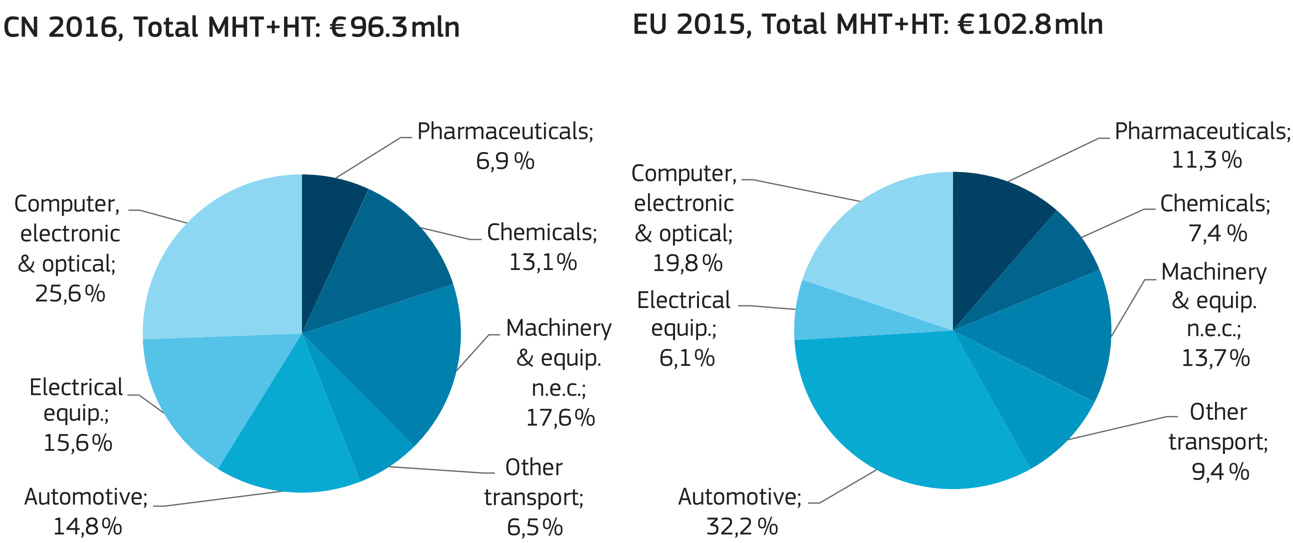


Figure 9.7: Shares of BERD in various medium-high-tech (MHT) and high-tech (HT) sectors in China and the EU
Source: China Statistical of S&T 2017, ESTAT

and optical products manufacturing. The EU is focused more on the automotive industry and pharma. The respective shares of the different sectors remain relatively stable *(Figure 9.7)*. According to this figure, industrial R&D by sector appears to be more diversified in China than in the EU. As seen, the opposite seems to be the case for patents and publications, where China shows greater specialisation than the EU *(Figure 9.5)*.

While offering a challenge, the still relatively narrow specialisation in terms of scientific and technological output does not have to limit China's ability to meet the targets it set out in MIC 2025 *(Chapter 1,* in particular *Table 1.1)*. China's industrial strategy to attain leadership in high-tech sectors such as wind energy, clean energy vehicles and photovoltaics tends to follow a pattern which does not start with technological leadership. Instead it starts out with relatively inferior technological capabilities. By flooding the domestic market with cheaper products, it can attain market dominance. Through incremental learning, joint ventures, (forced) technology transfers, acquisitions and the establishment of R&D facilities abroad, it can then upgrade its technological capabilities. By initially building on its technological strengths in some fields (including IT services), and gradually expanding its capabilities in others, it may achieve its long-term aims of technological leadership in many of the MIC 2025 priority areas.

9.4. Policy experimentation at regional level is key to China's research & innovation governance successes

As in Europe, R&D expenditure in China is geographically concentrated. R&D intensity is highest in China's east coast regions. The Beijing region, with an economy the size of Germany's, has almost double the R&D intensity of Germany, and of the target in the Lisbon strategy *(Figure 9.8)*. Regional government's public funding of R&D has overtaken central government funding.

Regional governments are actively engaged in R&I governance. There is also considerable room for R&I policy experiments at the regional level. Where successful, such approaches are scaled up and this process has thus played an important role both in policy learning and in the successes of China's R&I governance (Frietsch, *forthcoming*; Liefner, Wei, 2014; Breznitz and Murphee, 2010).

9.5. The budget of the Chinese research council is almost double that of the European Research Council

The Chinese research council (NSFC), widely credited as a good model for allocating science funding, has seen a sevenfold budget increase since 2008 *(Figure 9.9)*. This can partially explain the large increase in the output and quality of the Chinese science system. Other explanatory factors include the institutional reforms of the Chinese Academy of Sciences and of research universities, which have both also seen a major increase in their budget (Cao, *forthcoming*). Recent reforms of the R&I governance system have led to a greater separation between policy and project management[24] (Huang et al., 2016; Development Solutions, 2018: 6; Frietsch, *forthcoming)*.

The Chinese R&I system has undergone a number of reforms over the past 20 years, which, together with a large increase in investment, has led to an improvement in the quantity and quality of the output. Improvements in human capital, international collaboration and mobility have also played an important role in increasing the impact of China's scientific and technological capabilities. However, the Chinese R&D effort appears to be relatively narrow, specialised in a limited number of high-tech sectors. In order to meet the targets set in the Made in China 2025 strategy, China will have to broaden its capabilities to other fields.

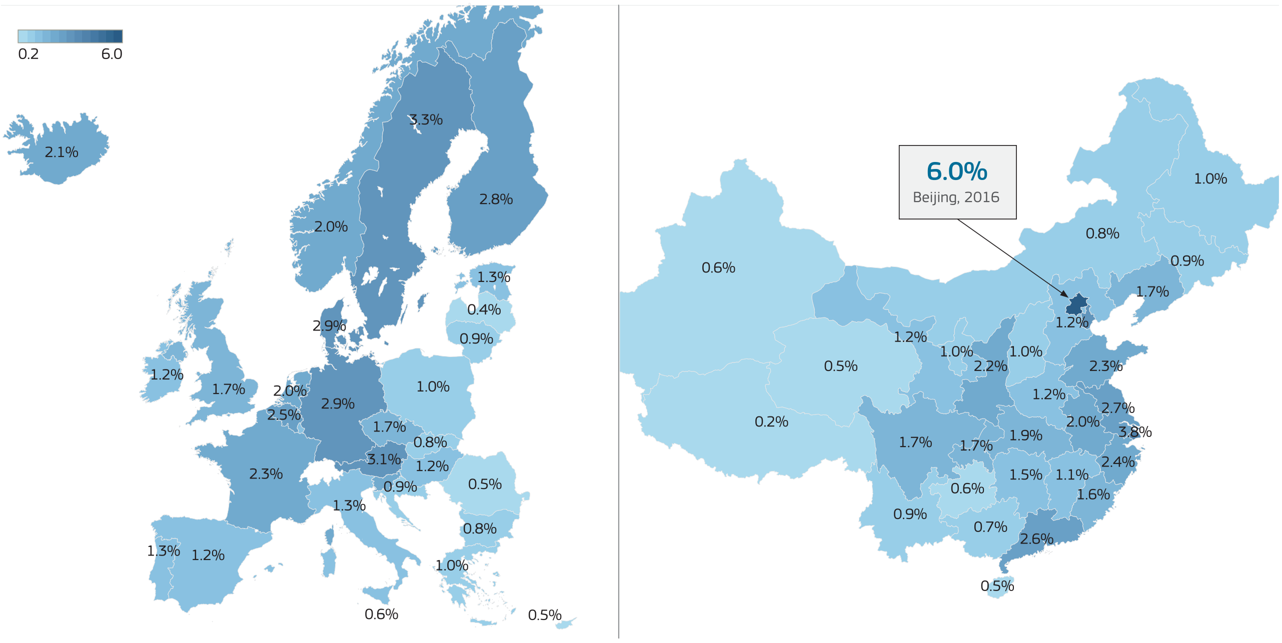


Figure 9.8: Regional GERD intensities in China and the EU
Source: Eurostat (left panel); China Statistical Yearbook of S&T 2017 (right panel)

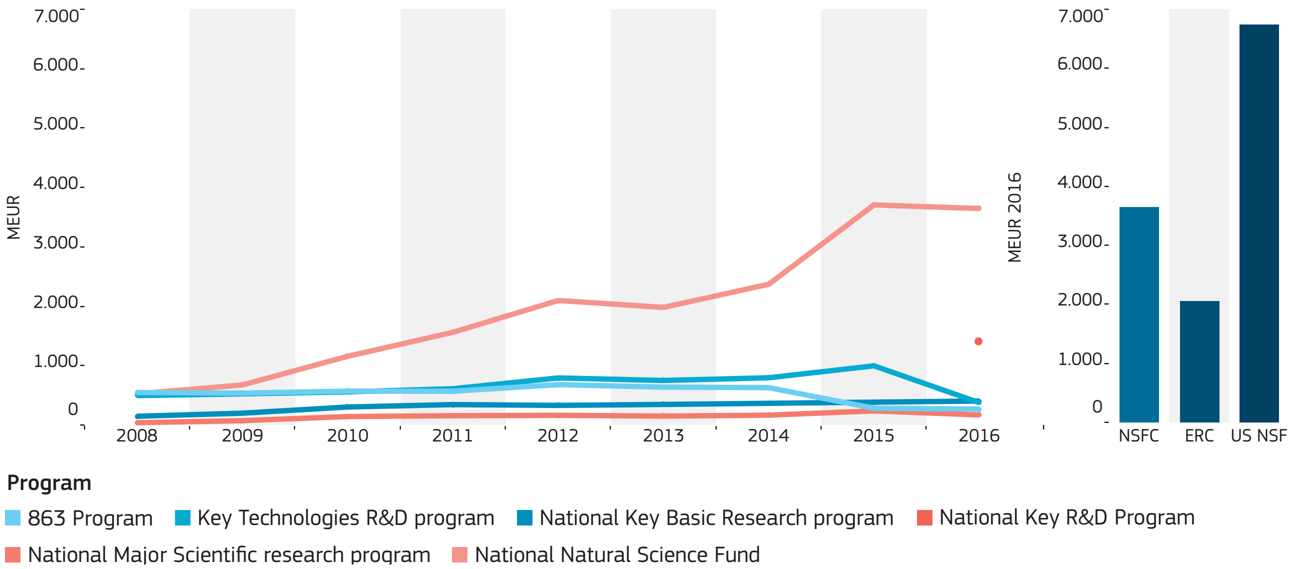


Figure 9.9: Budget for major research programmes
Source: China Statistical Yearbook of S&T 2017

THE US BENEFITS MORE THAN THE EU FROM CHINA'S RISE IN SCIENCE & TECHNOLOGY

10.1. EU-China co-publications increase less than US-China ones

As well as increasing its output, China's R&I system has also rapidly become internationalised. We can observe an exponential increase in international co-publications, which partially explains the increasing impact of Chinese scientific output.

The relative intensity of EU and US patterns of collaboration by field reflects US and EU scientific strengths. The US lead over the EU in Chinese co-publications is strongest in the life sciences. It is less pronounced in physics and engineering.

The abundance of high quality researchers is the most important factor for making R&D investment decisions in China

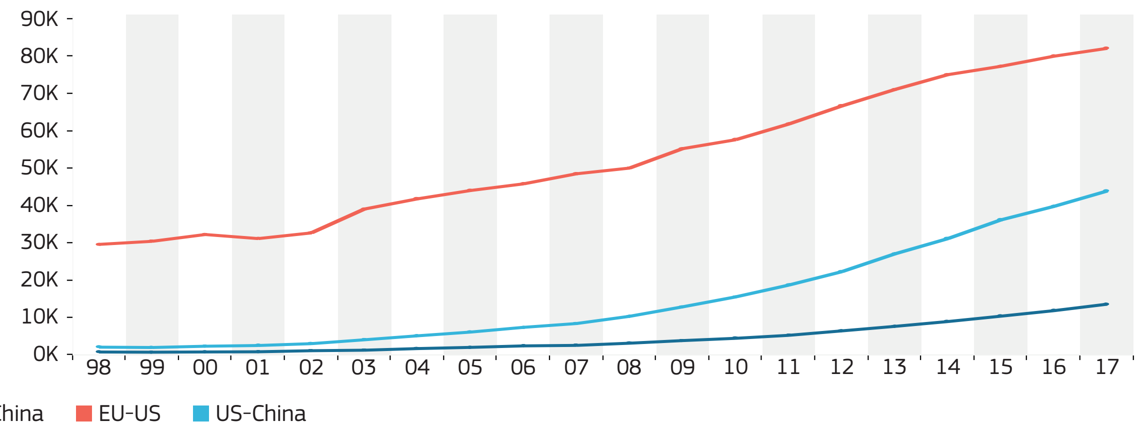


Figure 10.1: International co-publications between the US, EU and China
Source: International co-publications based on JRC elaboration of Scopus data

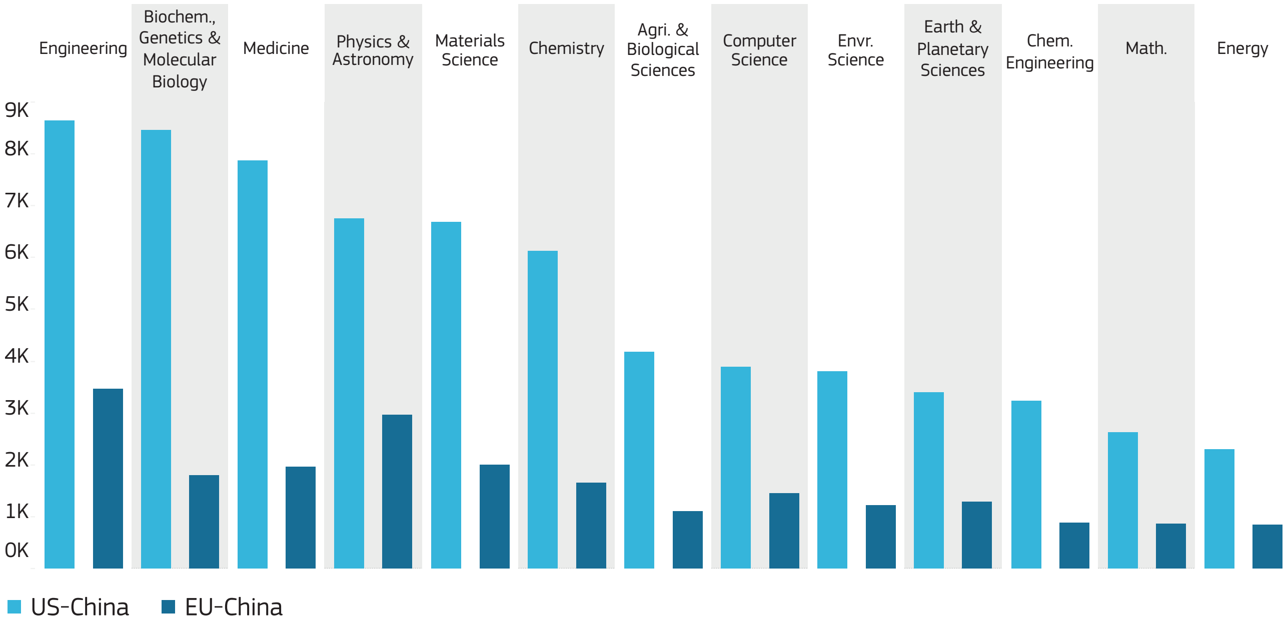


Figure 10.2: Chinese international co-publications by field
Source: International co-publications based on JRC elaboration of Scopus data

The relatively high numbers of international co-publications in engineering, physics, astronomy, material science and chemistry, as well as the limited collaborations in social sciences and psychology, are partially reflections of China's specialisation patterns. The relatively high level of collaboration in engineering, material science and molecular biology predates MIC 2025, but may help China to improve its scientific capabilities in priority fields.

10.2. China funds a large share of EU-China co-publications

International collaboration in research is thought to be driven mainly by bottom-up dynamics: individual researchers seeking the most suitable collaborators within their network. An important factor influencing the intensity of patterns of collaboration with China is thus the relative strength of the US and the EU in specific fields as shown in *Figure 10.2*. Funding and other forms of institutional support for collaboration may also be important. Wang and colleagues *(forthcoming)* show in *Figure 10.3* that funding by EU Member States is more frequently acknowledged than funding by the EU framework programmes. In the case of China,

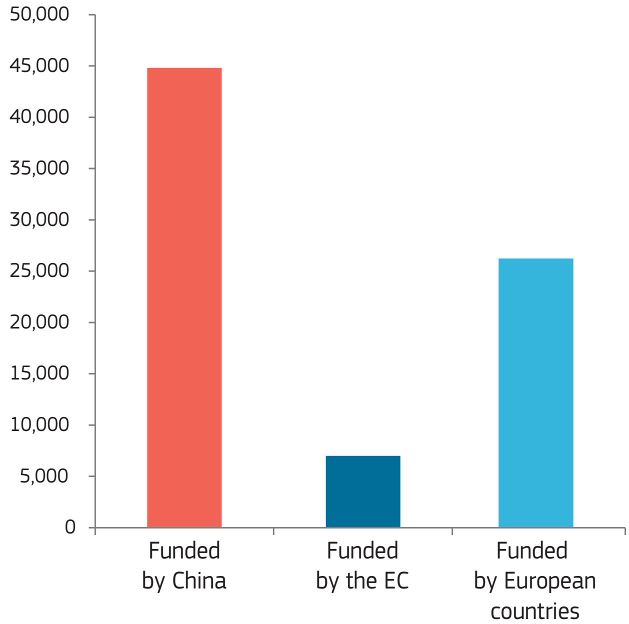


Figure 10.3: Funding acknowledgements in CN-EU co-publications
Source: Wang et al. *(forthcoming)* elaboration on Web of Science and CORDA data

participation in framework programmes no longer implies funding from the EU to Chinese scientists, as China pays for the participation of its researchers. Chinese programmes (including the NSFC) are even more frequently reported as a funding source for EU-China co-publications. The Chinese government thus has a clear interest in promoting EU-China collaboration. Given the lack

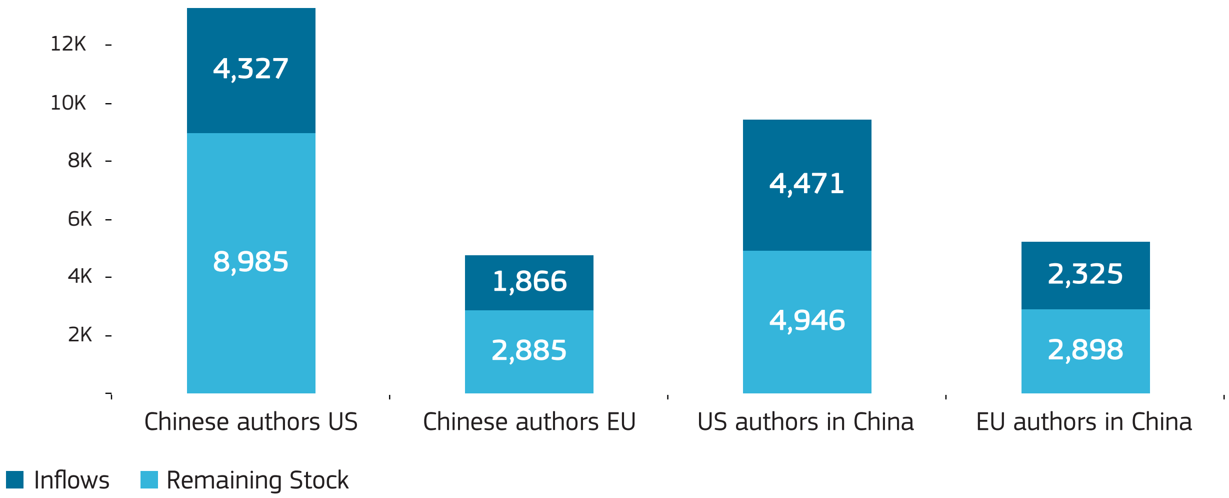


Figure 10.4: Scientific mobility between China, the EU and US

Source: Bibliometric mobility indicators are prepared by Elsevier Research Intelligence using Scopus data

of comparative data for the US, it is not clear whether Chinese institutional support is higher for collaboration with the US.

10.3. The US hosts many more Chinese researchers than the EU

Scientific mobility flows are thought to shape collaborative dynamics due to their effect on scientific social capital, i.e. the scientific networks of scientists (Jonkers, 2010). An important factor in the improvement of human capital in China is the increasing presence of researchers who have been trained in the EU and the US and have returned to China. To facilitate this return flow, China has introduced the world's most elaborate set of policy initiatives to attract its overseas talent back (Cao, *forthcoming).*

Chinese researchers overseas make an important contribution to the scientific human capital base in the US and the EU. There are no comparable statistical data on the mobility of Chinese researchers to the US and the EU. However, on the basis of bibliometric (publication) data, it is possible to make an assessment of the current stocks and flows[25]. *Figure 10.4* shows that the number of researchers who started publishing in China and then moved to the US is three times higher (approximately 13 000) than the number who moved to Europe (approximately 4 700).

The data showing US and EU authors in China (approximately 9 400 and 5 000 respectively) include many Chinese researchers who issued their first publication in the US or the EU before returning to China.

Most leading positions in the Chinese research system are now occupied by returnees: as early as 2009, over 60 % of PhD supervisors had foreign work experience. These returnees play an important part in shaping international R&D networks (see Cao, *forthcoming).* Returning and/or circulating highly skilled Chinese have also been important in building up high-tech companies in China and Taiwan (Saxenian, 2005).

The return mobility of Chinese students, scientists and engineers can thus play an important role in the transnational transfer of knowledge. In most cases this is a normal feature of the internationalisation of science. US analysts and government officials, however, also raise concerns about this development, especially when it concerns the illegitimate transfer of proprietary knowledge in the form of industrial espionage (Deutch, 2018). Whether or not this perceived threat is significant is unclear. However, there may be costs involved that partially offset the major human capital and collaboration gains involved in mobility flows.

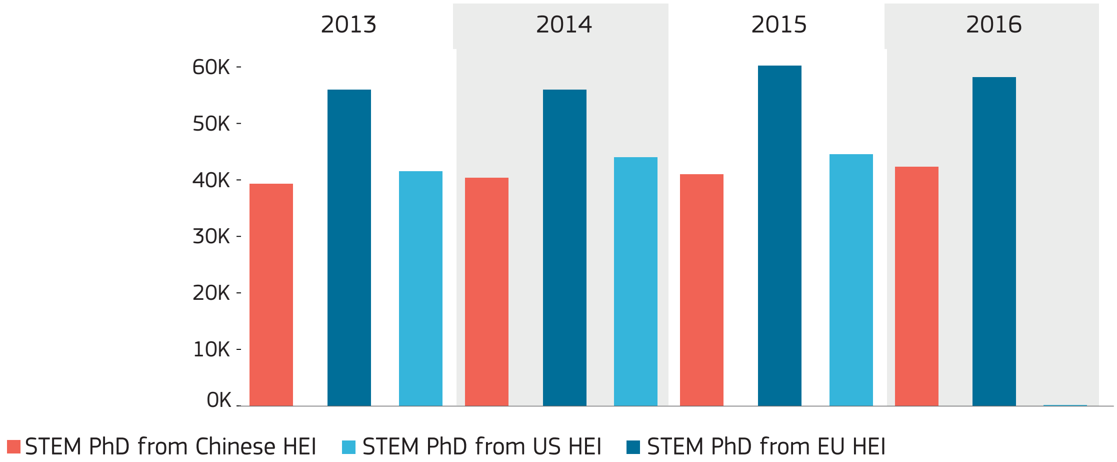


Figure 10.5: Number of STEM PhDs in the US/EU/China
Source: China Statistical Yearbook of S&T, Eurostat, US NSF S&E indicators

In addition to the return flows of overseas Chinese, the overall human capital situation in China has been improving considerably due to the rapid expansion of output from its research universities. The annual number of Science Technology Engineering and Mathematics (STEM) PhDs graduating from Chinese universities has grown by 450 % since 2000 *(Figure 10.5)*.

With around 40 000 STEM PhDs graduating annually, China is currently close to the US, while still being well behind EU universities (by about 37 %). The quality of output from China's higher education system has been increasing considerably as a result of the large investments and the reform of China's research universities through the 211 and 985 programmes. In 2015, these programmes were replaced by the Double First Class programme, which aims to take five Chinese universities into the world's top 20 by 2050 (Cao, *forthcoming*).

10.4. EU firms benefit less than US firms from China's rise

According to the GLORAD/GLOBAL database, Chinese companies have established or acquired 235 R&D centres outside China, of which 56 are in the US and 86 in the EU. The GLOBAL database holds records on 850 R&D laboratories operated in China by foreign multinational corporations (MNCs). Of these, 324 are from large MNCs headquartered in the US and 349 from the EU[26]. In recent years, top EU R&D investors surveyed have consistently indicated that they expect to invest more in R&D in China. However, in reality their investments have remained at a stable level. More of these firms state that it is the abundance of high-quality researchers *(Figure 10.6)*, rather than their low labour costs, which is important for making decisions about R&D relocation to China.
EU R&D investors also indicate that proximity to technology poles and access to specialised R&D knowledge are important factors for locating R&D investments in China.

Figure 10.7 shows that foreign firms are increasingly tapping into China's public knowledge base through public-private collaborations, leading to co-publications. However, it is also apparent that EU firms are significantly lagging behind US firms in this area. Analyses of patents show that neither US nor EU firms engage in a large degree of collaboration on patents with inventors based in China.

As well as foreign firms establishing laboratories in China, Chinese companies are also increasingly establishing labs abroad. Huawei, for example, already had 16 R&D centres outside China in 2015 (Von Zedtwitz and Gassman, 2017).

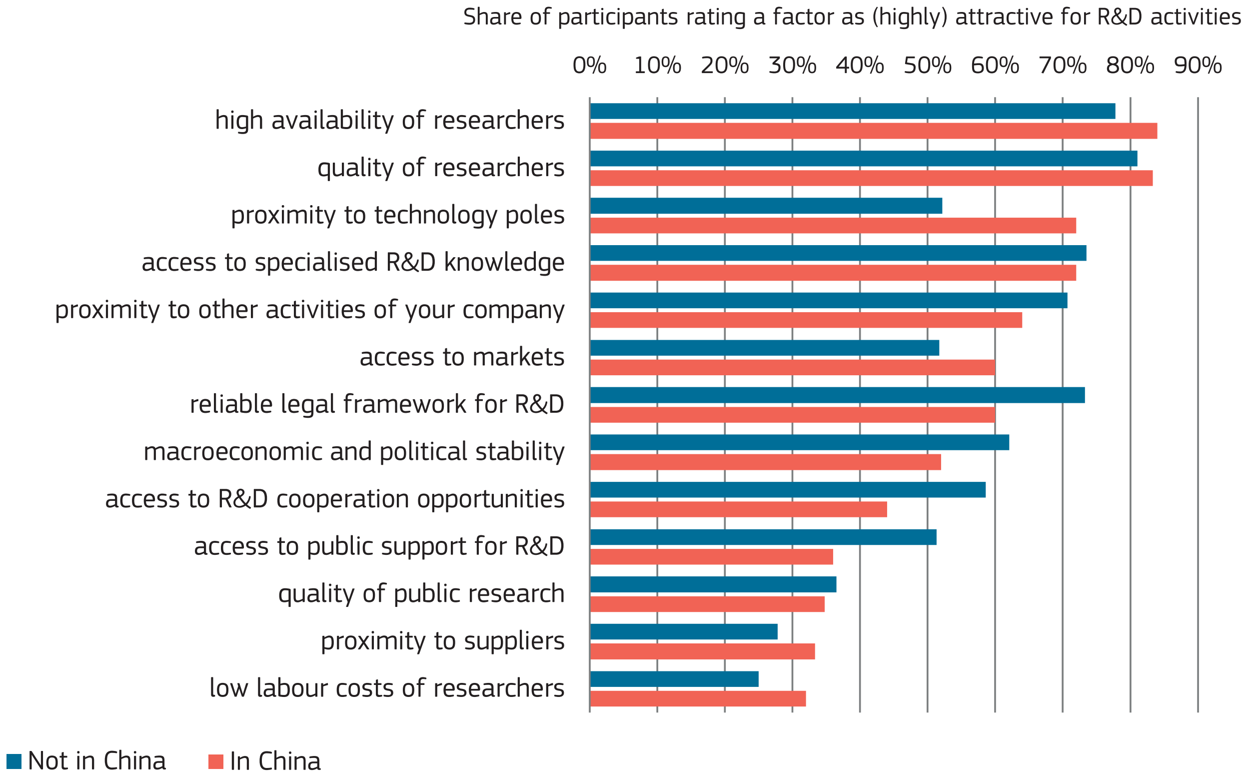


Figure 10.6: Sectoral attractiveness for R&D activities
Source: JRC (EC)

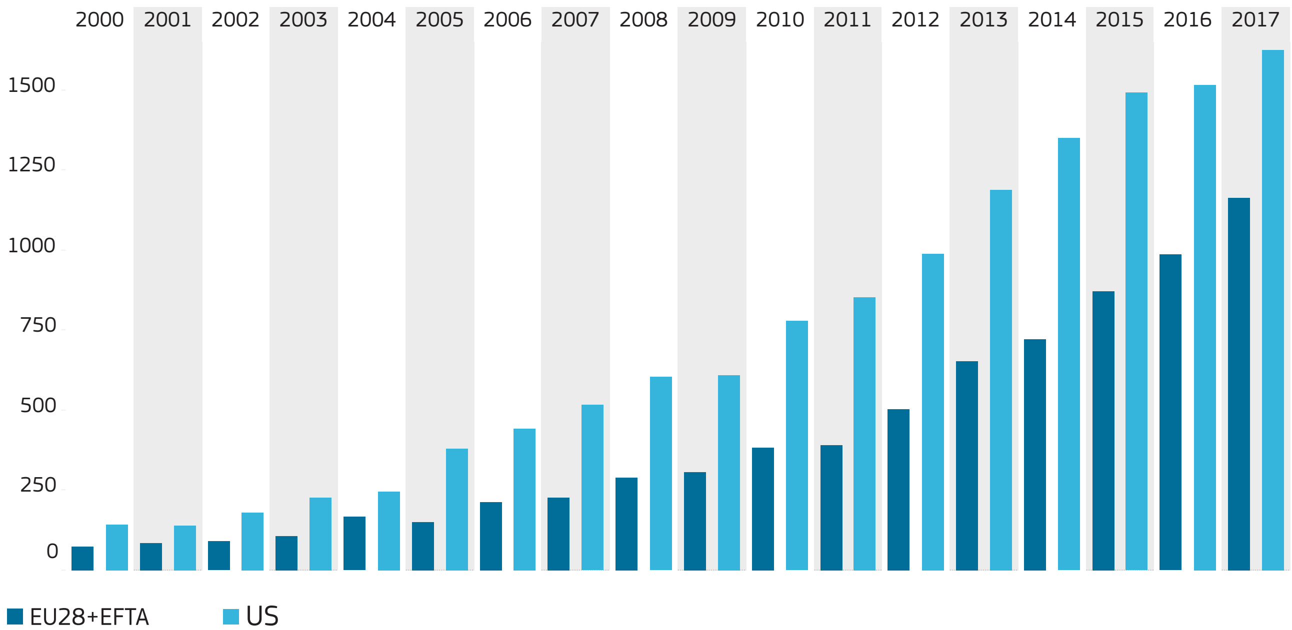


Figure 10.7: Number of co-publications between Chinese researchers and EU/US firms
Source: Computations based on Frietsch *(forthcoming)*

Figure 10.8[27] shows the origin of foreign inventors in patents owned by top R&D investors based in China. Among the top Chinese R&D investors, the preference for US partners in applications to the US Patent and Trademark Office (USPTO) is much stronger than the preference for EU partners when applying to the European Patent Organisation (EPO).

This may be partially due to the industries in which these firms are active. Top Chinese R&D investors have a preference for the US for sourcing knowledge in the field of ICT hardware and equipment, where most foreign patents are filed. The EU is more important in automobiles and parts. This partially reflects the specialisation patterns of the US and the EU, while returning to the general message of this chapter, that US firms and research organisations benefit more from China's rise than their EU counterparts.

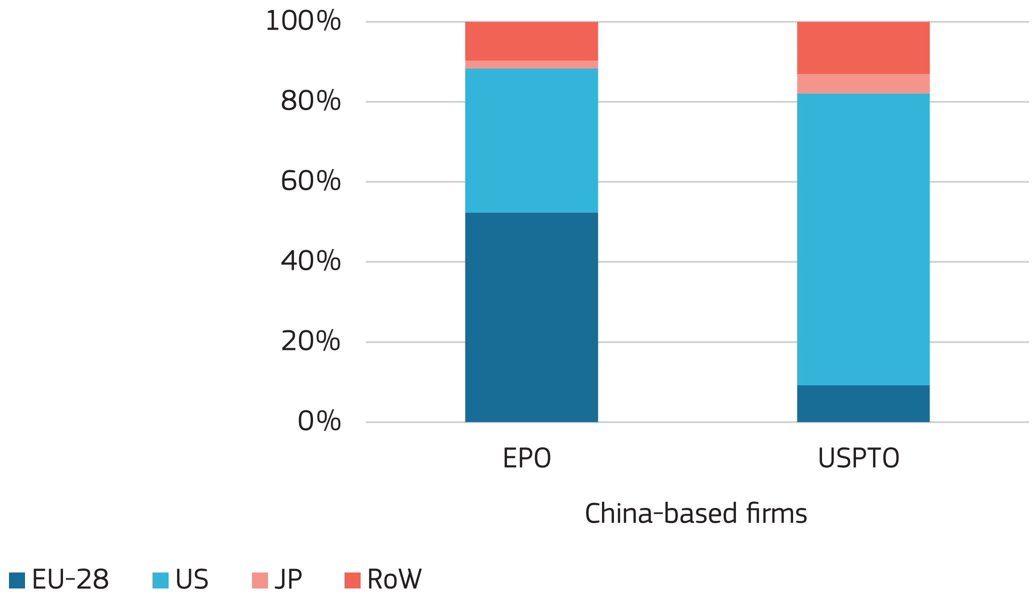
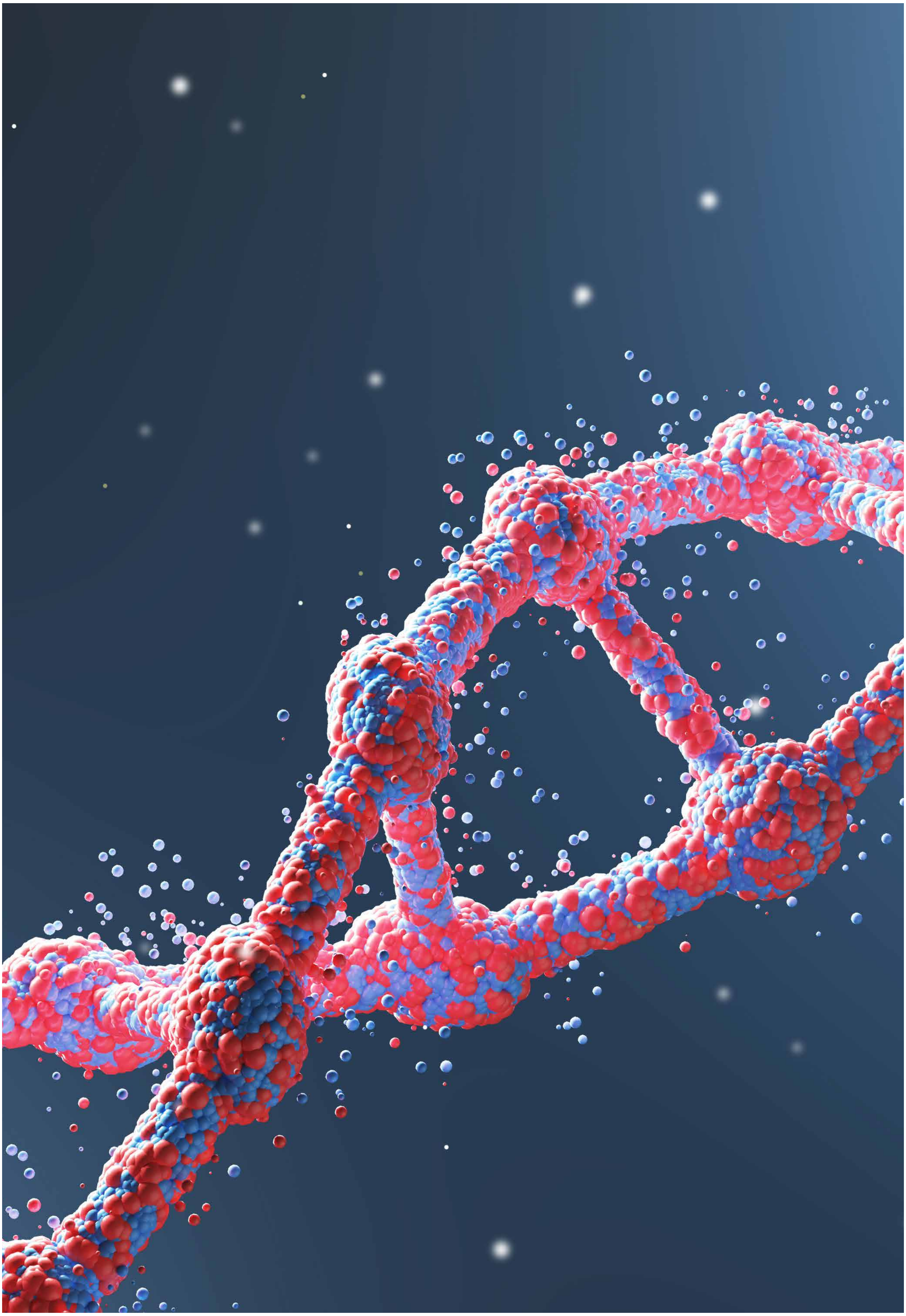


Figure 10.8: Foreign inventions with China based R&D investors (2005-2015)[27]
Source: JRC (EC)



GENOMICS

11.1. China hosts about 20-30 % of worldwide sequencing capacity

The current trend in healthcare is to move towards a personalised patient-centric approach. The key driver in this change is the advance in genomics, in terms of DNA sequencing speed and cost, storage capacity and big (DNA) data analysis. While in 2003 China contributed only 1 % to the sequencing of the human genome project, by 2010 it hosted more sequencers than the US, accounting for about 20-30 % of the world's sequencing capacity (Cyranoski, 2016). Furthermore, China has now developed its third-generation sequencing platform, GenoCare, which enables completion of the whole genome sequence (WGS) within 24 hours for USD 100, surpassing the so-called next-generation sequencers (NGS) that involve several days' work at a cost of about USD 1 000.

> The EU and the US invest more in basic genome research than China but China is patenting more

11.2. The Chinese DNA sequencing market is growing fast

The global DNA sequencing market is predicted to reach USD 22 billion by 2020 and the Chinese government will invest USD 9 billion over the next 15 years, surpassing the Obama administration's USD 215 million investment in 2016.

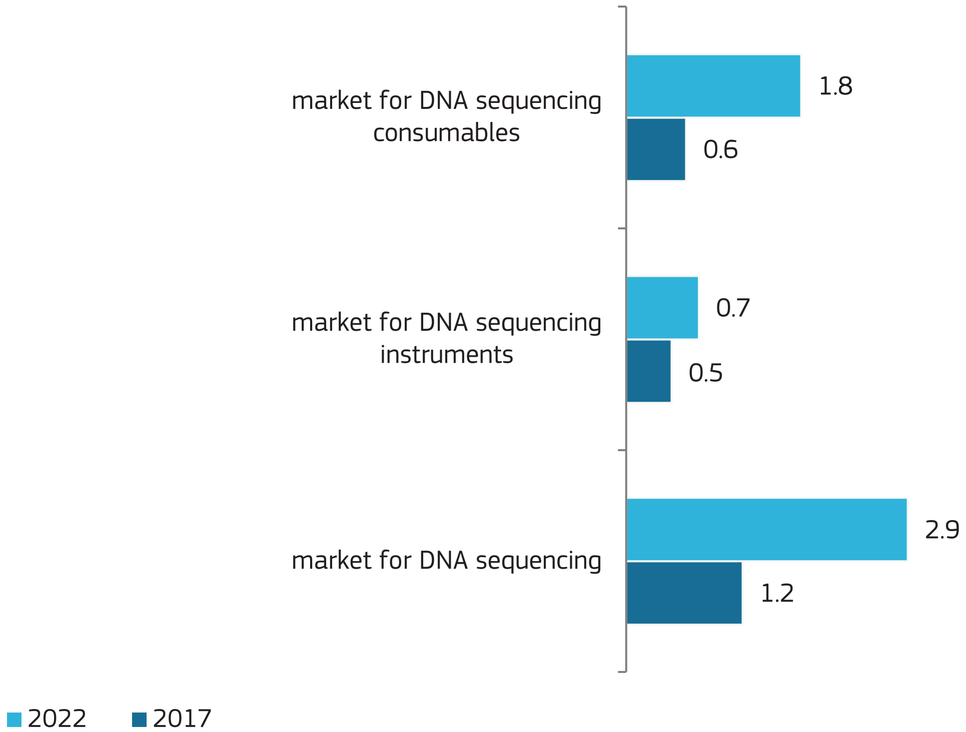


Figure 11.1: China's DNA sequencing market ($bn, 2017; estimate)
Source: BCC research (2018)

The Chinese market for DNA sequencing totalled USD 1.05-1.2 billion in 2017, and it is expected to reach USD 2.68-2.9 billion by 2022 (BCC research, 2018) *(Figure 11.1)*.

Given this large and growing market, leading EU and US producers of genome sequencing equipment are moving operations to China. China has identified genomics as a key strategic field in its 13th Five-Year Plan (2016-2020) for the country's economic and social development (Deng, 2017). China launched one of the world's largest genome sequencing projects in 2017. It will collect genomic data from 100 000 people from different ethnic backgrounds and regions. The Beijing Genomics Institute (BGI) has also announced its intention to sequence one million animal genomes and one million micro-ecosystems, while the eastern province of Jiangsu has unveiled a plan to sequence the genomes of one million people (Yicai, 2017).

11.3. China focuses more on patent applications than on basic research

As in other research areas, the EU and the US invest more in basic genome research than China. The EU and the US are leading research in the field of NGS and WGS *(Figure 11.2)*[28]. However, China focuses more on application activities than on basic research. This is confirmed by analysing the number of patents submitted: if patent applications to the State Intellectual Property Office (SIPO) are included, China has a significantly larger output than the US and the EU.

11.4. Chinese regulations facilitate research & innovation activity in genomics but may limit the sharing of data with foreigners

Chinese patent regulations differ from those of the EU and the US, e.g. it is easier to apply for gene patents. Indeed, in 2001, Shanghai Joint Gene Technology Co. Ltd. applied for more than 3 700 gene patents with a potentially high impact

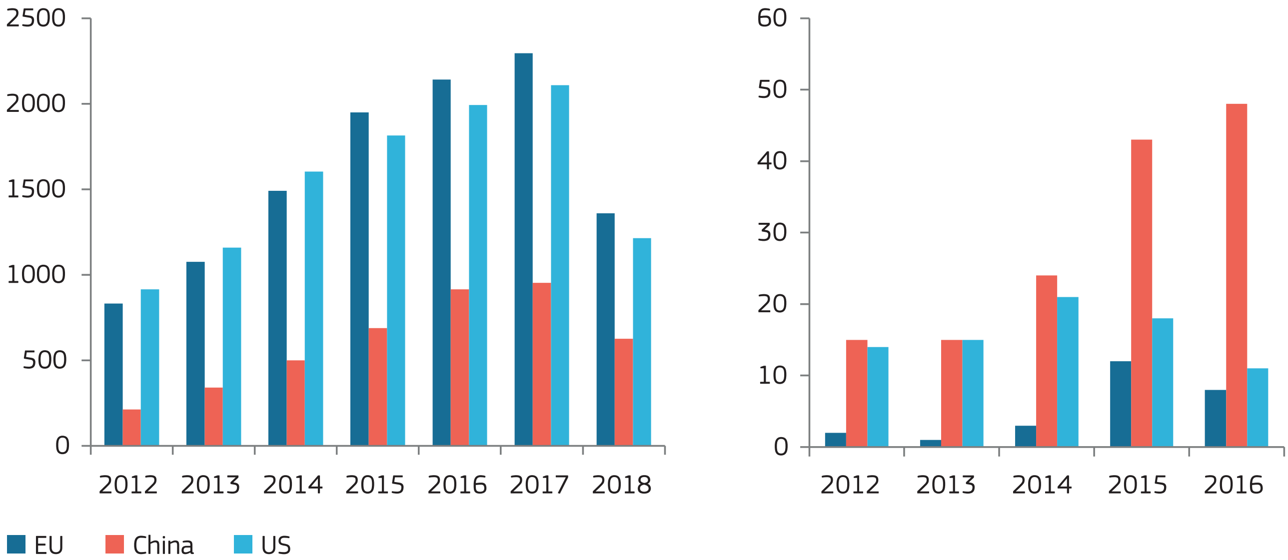


Figure 11.2: Number of scientific articles (left panel) and patents (right panel) on NGS & WGS
Source: Technology Innovation Monitoring tool (TIM)

on medical diagnosis and the development of medicines (WHO, 2005). Legal standards also differ when it comes to handling privacy issues. Protection of genomic data is mainly based on the perception that Chinese human genetic resources are the state's collective property. This both has implications for the data that can be collected inside China, and imposes potential limitations on data sharing with foreign collaborators (Chen and Song, 2018).

11.5. Made in China 2025 aims to further increase the genome sequencing storage capacity

Following the expansion of genome projects, the amount of genomic data has increased exponentially. The volume of data produced worldwide is comparable to that produced by astronomy, Twitter or YouTube (Stephens et al., 2015). This genomic information is stored in databases located in different countries. The regional distribution of the 20 most relevant organisations is summarised in *Figure 11.3*. China's low storage capacity is addressed in the Made in China 2025 strategy. The Bio-informatics Data Center of the China National GeneBank stores one petabyte (1PB) of raw data on human and non-human genomes (Cyranoski, 2016). It has a storage capacity of 20 million traceable bio-samples and complies with international standards, including ISO standards. It will provide support to GigaDB, a Chinese repository of genomic data and tools accessible worldwide. A biomedical data analysis centre in Nanjing will have a storage capacity of 52 PB to cover the health records of 80 million individuals (Yicai, 2017). Finally, BGI's Chinese Millionome Database will store high-quality Chinese genomes (under-represented in the European and American databases) to be used as controls for medical research and population-oriented clinical and drug applications.

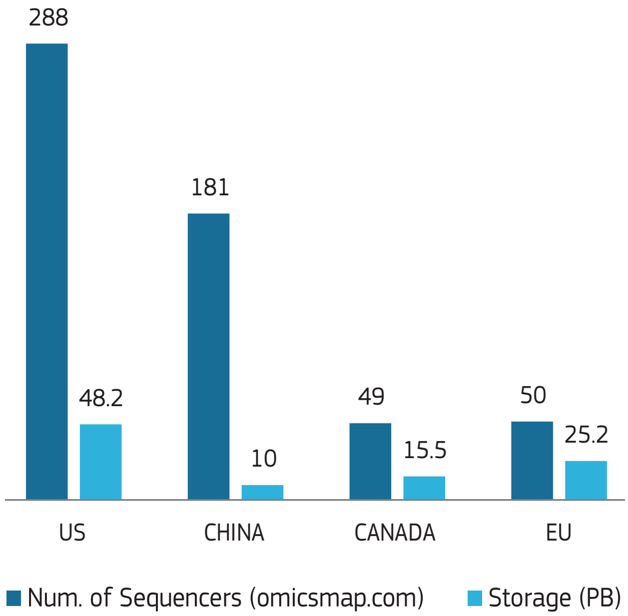
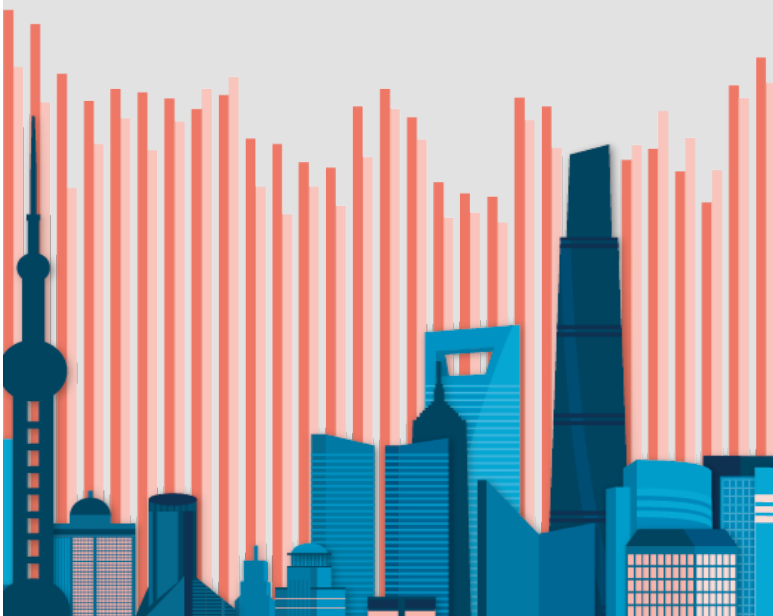


Figure 11.3: Sequencers and storage for the 20 most relevant organisations
Source: Data from Stephens et al. (2015)

Future perspectives: Metagenomics and genetic fingerprints

Information available in DNA databases is a strategic asset in personalised medicine. In the near future, the genomic data will be expanded with metagenomics information. The addition of other data, such as on the microbiome or the epigenome, will ensure the possibility of obtaining the 'ge-netic fingerprint' of each individual and eventually his/her relatives (Kaplanis *et al*, 2017). This data can be combined with geospatial information related to, for example, environmental exposure (Hooper *et al*, 2012) or diet and any other health factors, in order to have a broad overview of an individual's personal track record.



ARTIFICIAL INTELLIGENCE

12.1. China has become a global power in digital technologies

The field of artificial intelligence (AI) is experiencing a period of intense progress, due to the consolidation of several key technological enablers. The case of China is particularly relevant, since the country is already a leading global force in the digital economy, fuelled by three main factors: a large and young Chinese market, enabling rapid commercialisation of digital business models; a rich digital ecosystem, which is quickly expanding beyond the hegemony of a few large companies; and the strong support of the government as an investor, a consumer of digital technologies and a provider of access to key data for companies, with favourable conditions.

12.2. Highly focused policies and initiatives confirm Chinese government's support for artificial intelligence

The framework for the development of such a targeted innovation ecosystem depends largely on policies and initiatives created by government bodies. For instance, involvement of publicly controlled companies, innovative purchases by government bodies, enforcement of all types of regulations and regimes (such as intellectual property), degree of interaction between the industrial-military complex and the civil sectors, relationships between local and global innovations, promotion of human capital, availability of financing, and facilitation of access to data. In the case of China, this public role is even more relevant. Since 2014, the government has launched

> AI represents the first Chinese success to independently create a home-grown fully-fledged innovation and industrial ecosystem

a series of key national economic initiatives that touch upon AI *(Figure 12.1)*: the 13th Five-Year Plan, the Made in China 2025 initiative, the Robotics Industry Development Plan, and the Three-Year Guidance for Internet Plus Artificial Intelligence Plan. The overall goal of these plans is to make China the leading figure in the world of AI by 2030. The main and most recent government initiatives related to AI outline how China's State Council intends to develop AI inside the country and how it aims to become a global innovation centre for this technology by 2030. Their timeline is also interesting, because it displays how policies and initiatives started at industry level slowly move up the value chain, and also includes applications and the consumer perspective. Indeed, the whole value network has been covered, providing a holistic perspective on how to develop AI. It is particularly interesting to follow the developments that allow for companies in different sectors to share and access data, to train and look for newer and better algorithms.

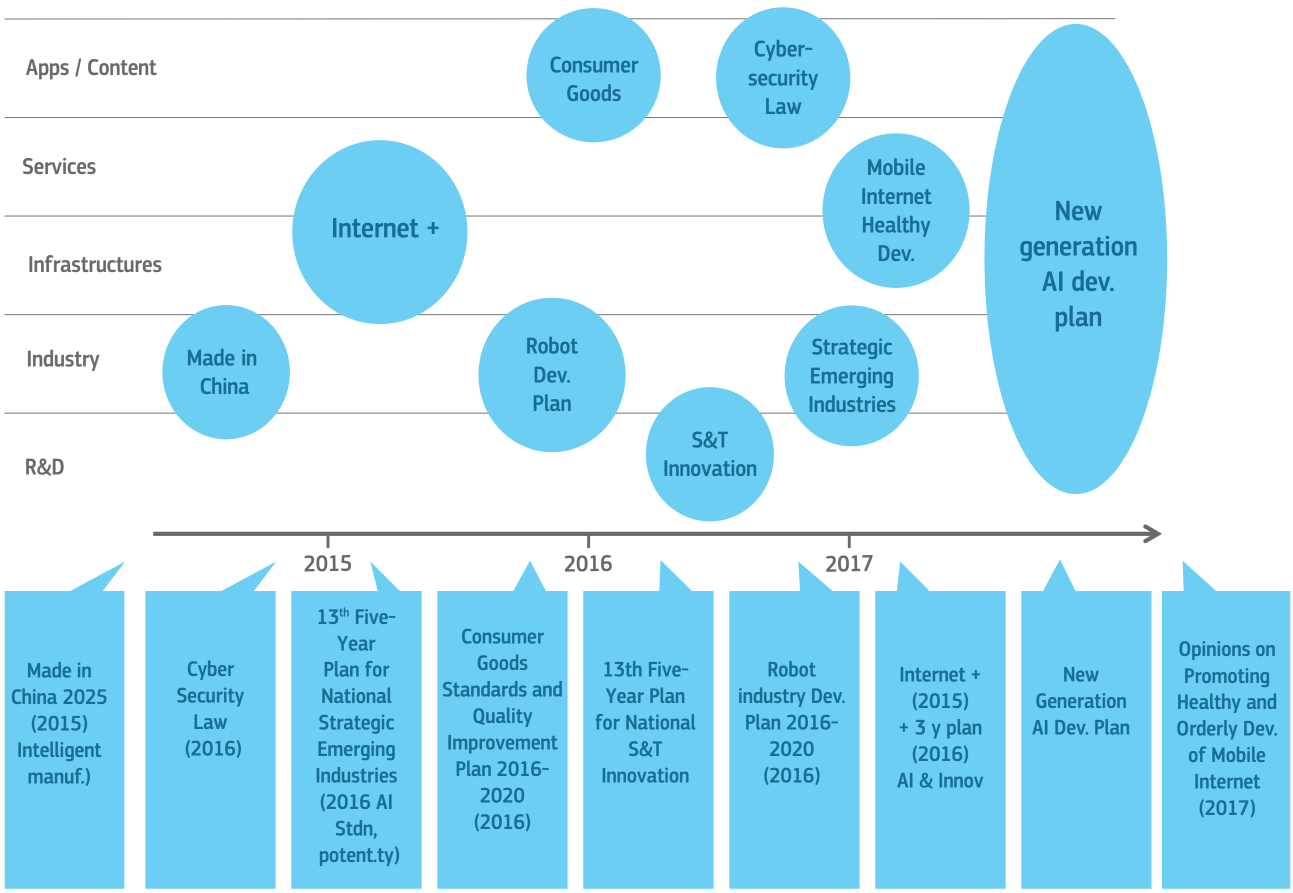


Figure 12.1: Chinese initiatives to support an AI ecosystem
Source: Feijoo *(forthcoming)*

12.3. China's industrial innovation ecosystem for artificial intelligence is vibrant and built around large companies

In the past, when dealing with other new technologies, the government first allowed experimentation and new business models. Only when some degree of success was attained were these new solutions aligned with societal objectives. Unlike in the past, in the case of AI the development of the sector relies on a plan that encompasses all relevant players within an ecosystem, from universities and research centres to existing companies and new firms in the entrepreneurial/innovation environment. AI thus seems to represent the first real Chinese attempt to independently create a fully-fledged home grown innovation and industrial ecosystem. AI, however, is not an isolated ecosystem and it will interact and benefit from developments in other successful innovations such as ecommerce or mobile payments, as well as cloud computing, industry 4.0, robotics, Internet of Things (IoT), blockchain, microelectronics and IT security ecosystems (Networks Asia, 2018). The case of cloud computing is particularly relevant, since it is expected that a considerable part of AI services will be provided from the cloud. Therefore, there will be significant alignment of market developments for both technologies. Another new ecosystem to watch together with AI, and linked to industry 4.0, is robotics. This is an area where China, with the exception of visual and voice interfaces, is somewhat behind the US and the EU.

In 2017, China's AI market reached CNY 23.7 billion. This is 67 % more than in 2016. The three largest segments are computer vision (34.9 %), voice (24.8 %) and natural language processing (21 %). Hardware and algorithms together account for less

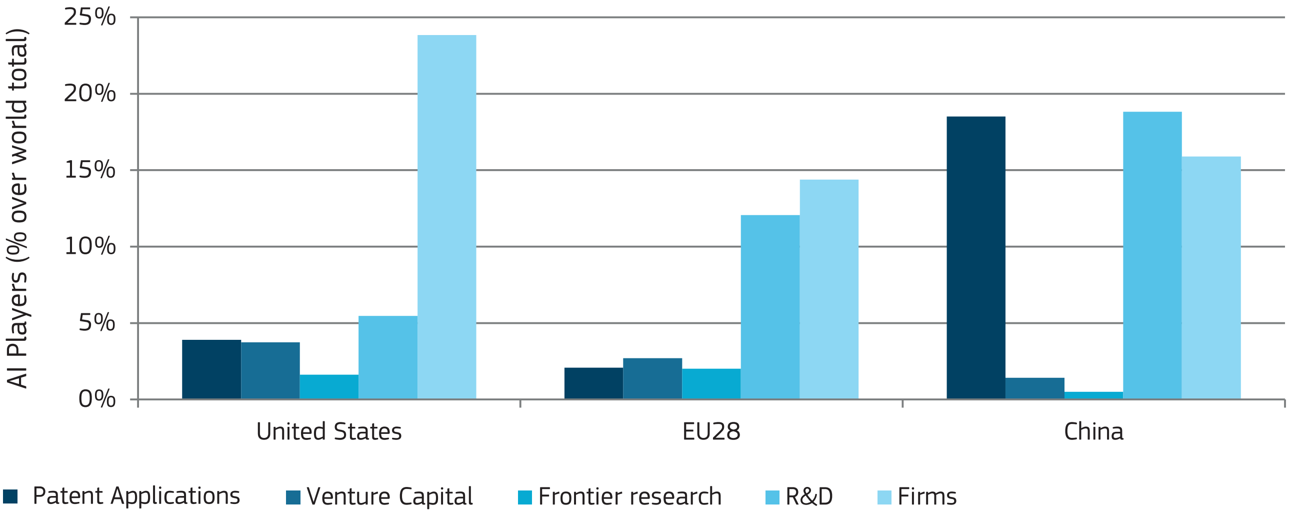


Figure 12.2: AI players by type of activity in US, EU28 and China, 2009-2018
Source: JRC Computations

than 20 % of the Chinese market. The market is expected to grow further by 75 % in 2018. China's AI publications as a percentage of the global total increased from a little over 4 % in 1997 to around 28 % in 2017 (CISTP, 2018). *Figure 12.2* shows the share of AI players in the US, the EU-28 and China following the JRC TES methodology (Craglia et al, 2018). It shows that China has a relatively large number of firms, R&D investors and actors filing AI patents.

The relevant large companies for AI in China are basically the big three internet giants: Alibaba, Baidu and Tencent. A second group of large companies partially involved in AI includes the ride-hailing company Didi Chuxing, the on-demand services provider Meituan-Dianping, the mobile handset and network equipment manufacturer Huawei, and the speech and language recognition firm iFlytek. A third and last group are large foreign tech companies, mostly from the US, that have set up research centres and joint ventures in China to position themselves in what they think could be a promising innovation landscape. No large European company seems to hold a significant position in the Chinese AI innovation ecosystem. The limited number of top companies in AI in China results in investors betting on two to three dominant players[29]. These dominant players usually capture all the emergent start-ups to ensure the continuation of their dominant positions, in particular in general consumer-related markets.

The Chinese government actively backs promising AI projects and infrastructures

Two key government measures to promote AI are:

- Providing access for eligible companies to its database of facial and personal information, composed of about 1 700 million entries (1 400 million Chinese citizens and 300 million foreigners);
- Implementing AI-based solutions for public security and safety projects across the country.

The government is also the main driver behind two major initiatives:

- The 'social credit system' aims to combine all the socially relevant activities of citizens, to rank individuals and provide them with incentives for enhanced behaviours;
- SkyNet is a police/security system to identify suspects and criminals and even anticipate potential sources of conflict. It consists of video surveillance systems, a database of suspects and interesting subjects, and the technology to check identity against the identity information already held by public bodies.

Similar state- or firm-led projects may not be possible in the EU or the US due to legal, cultural and potentially ethical considerations.

ADVANCED MANUFACTURING AND INDUSTRIAL ROBOTICS

13.1. China accounts for 30 % of the industrial robotics market and this share is growing fast

Worldwide sales of industrial robots rose by 10 % per year between 2006 and 2016 (CAGR) (Statista, 2018) *(Figure 13.1)*. Since 2010, the demand for industrial robots has accelerated considerably, due to the ongoing trend towards automation and continued innovative technical improvements in industrial robots. A total of 74 % of global robot sales occurred in five countries: China (30 %), the Republic of Korea, Japan, the US and Germany (IFR, 2017).

By 2020, Chinese companies will account for 40% of all industrial robot sales

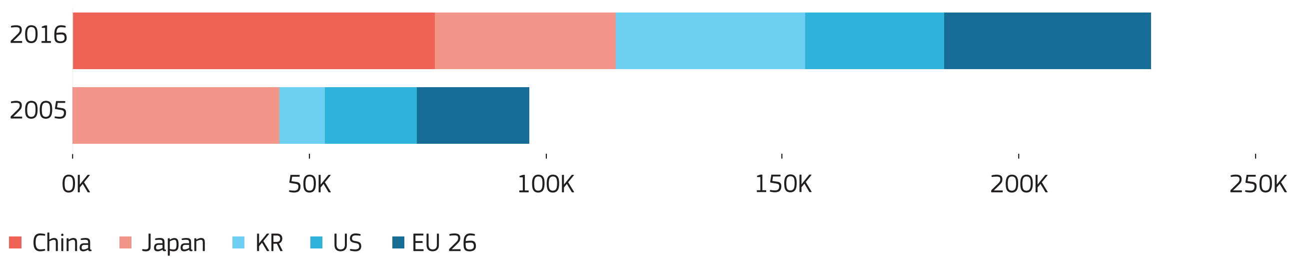


Figure 13.1: Sales of industrial robots
Source: JRC based on IFR2017

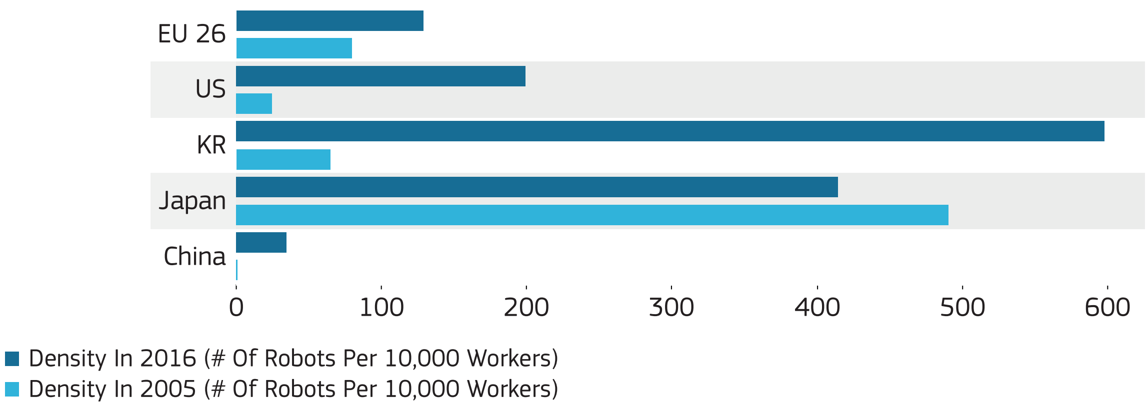


Figure 13.2: Robot density
Source: JRC based on IFR 2017

Figure 13.2 shows the number of multi-purpose industrial robots per 10 000 persons employed in manufacturing industries. In 2016, the most automated countries in the world were the Republic of Korea, Singapore, Japan and the US. China, one of the largest acquirers of industrial robots, does not yet appear among the countries with a high robot density. However, it is an emerging and dynamic market for robotics. While in 2016 China had five times fewer robots per employee than the EU, it is estimated that by 2020 China will account for 40 % of all industrial robot sales (IFR, 2016). As discussed in Chapter 4 on M&As, the German industrial giant Kuka is now under Chinese ownership and China is where Kuka is focusing on growing its business (Handelsblatt, 2018). This may partially explain China's high market share in global robotic sales.

13.2. By 2020 China will account for 40% of all industrial robotic sales

The Chinese government is supporting this expansion, providing subsidies, tax breaks and rent-free land for manufacturers. In addition to the MIC 2025 strategy, the government has also released the Robotics Industry Development Plan, a five-year plan to rapidly expand the country's industrial robotics sector. China is expected to increase its annual sales of industrial robots by 15-20 % between 2018 and 2020 (IFR, 2017). By 2020, China wants to be able to manufacture at least 100 000 industrial robots annually. China has more than 40 new robot industrial parks under construction (CNCB, 2017).

13.3. The technological capabilities of Chinese industrial robotics firms are still well behind the EU and US

Table 13.1 displays the patenting activity of the top Chinese, EU and US R&D performing companies in advanced manufacturing technologies, including industrial robotics. Chinese scoreboard companies have filed only a fraction of the number of patent families for Advanced Manufacturing-related Technologies (AMT) filed by EU and US firms during the three-year period of analysis. In contrast to firms from both the EU-28 and the US, Chinese scoreboard firms do not specialise in the development of AMT. A higher share of AMT applications to SIPO are filed by Chinese applicants than for patents in general, which may provide an indication either of their quality or of the perceived potential for exporting this knowledge outside China. The shares of Chinese AMT patents filed at EPO are also higher than the average for Chinese patents overall. EU companies file a higher than average proportion of AMT-related patent families at SIPO, reflecting the growing importance of the Chinese industrial robotics market. Nokia, Ericsson and Alcatel-Lucent[30], active in the telecommunications industry, own the largest patent portfolio in AMT, coupled with a significant presence of Chinese inventors (9-13 %).

	Patent families in Advanced manufacturing	RTAs in Advanced manufacturing
China	122	0.43
EU28	1 664	1.14
US	2 764	1.29

Table 13.1: Advanced manufacturing related technologies
Source: JRC - OECD, COR&DIP (2017)

13.4. One single Chinese company holds around 70 % of the world drone market

The industrial robotics market, which has traditionally represented the robotics industry and been led by Japanese, European and US robotics manufacturers, is giving way to non-industrial robots, such as personal assistant robots, customer service robots, autonomous vehicles, and unmanned aerial vehicles (UAVs – or drones). Out of 10 of the biggest drone companies (including manufacturers of components for drones), 7 are US companies. However, around 70 % of the commercial drone market is held by a Chinese company - DJI Innovations. Though the US still has the upper hand when it comes to drone technology, China is not far behind and is actively working to catch up. China poses a threat to US dominance in the drone industry largely because of its ability to make more products at lower prices, while constantly improving the quality of the products. China has seen a dramatic increase in the number of drones it has sold to foreign countries in recent years. Lack of regulatory constraints, lower prices, intensive investments (including plans to set up factories overseas in order to bypass export restrictions entirely), as well as attempts to increase its satellite capabilities, are factors that could make China the dominant player in the drones market in the near future.

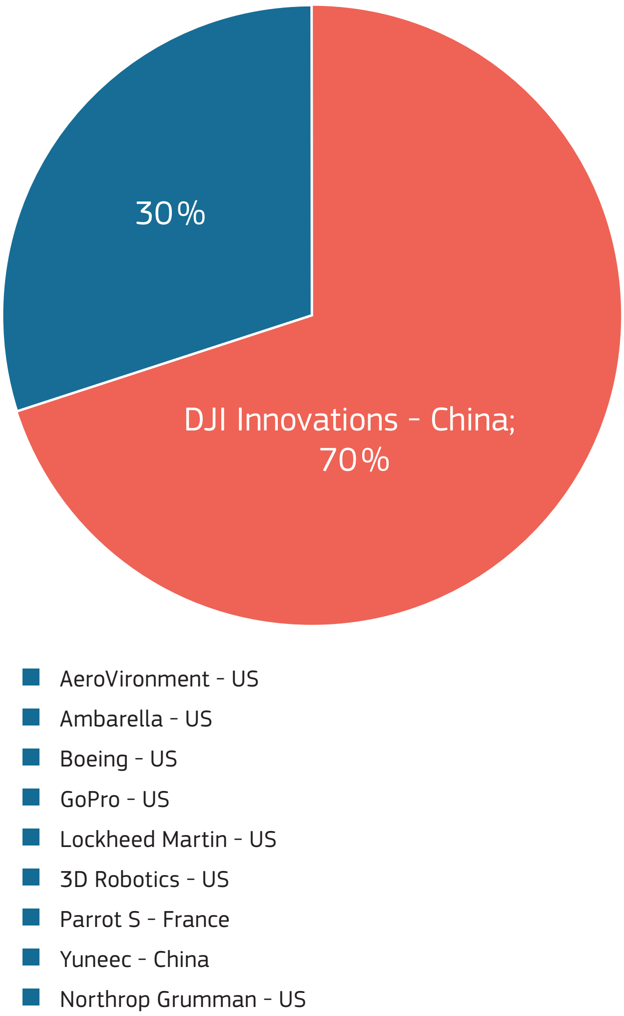
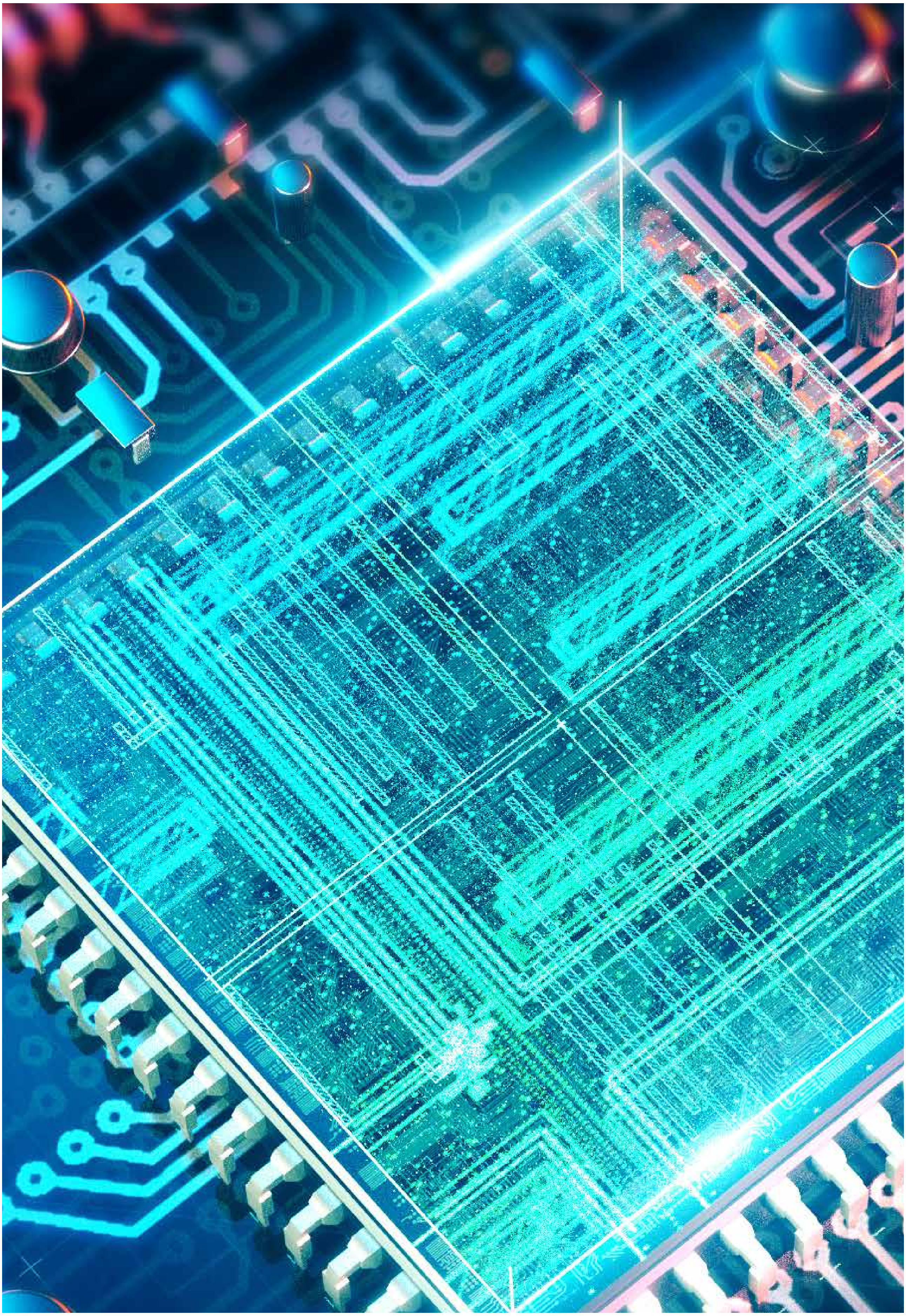


Figure 13.3: Market shares for commercials drones
Source: JRC based on Business Insider



QUANTUM TECHNOLOGIES

14.1. Public support for quantum technologies has made China one of the main players worldwide

New technologies, based on quantum effects confined until now to university laboratories, can lead to transformative applications, but they require a long-term mindset and high tolerance for risk: promotional policies therefore constitute a key factor to help transition to real-world implementation. China's public support for Quantum Technologies (QTs) began at the turn of the century, and has since continued unwavering. In 2015, combined worldwide spending on non-classified QTs research amounted to around EUR 1.5 billion: China was among the top contributors, at EUR 220 million, alongside the EU, the US, Canada, Australia and Japan (McKinsey, 2015). QTs have been included in the Chinese Five-Year S&T plan 2016-2021 as one of the top 10 national scientific priorities.

> China is building a national laboratory for quantum information science with an initial investment of €1 billion

14.2. China has deployed extensive quantum-secure communication networks

In the communications domain, the most technologically mature application of QTs is Quantum Key Distribution (QKD), which enhances communications security by enabling the transmission of an encryption key, the privacy of which is guaranteed by basic laws of physics. QKD pilots are being installed in several countries, but none can be compared to the Chinese deployment in terms of reach and number of interconnected nodes. A 2 000-km quantum backbone and several metropolitan networks have been built and are now connected to the world's first quantum satellite. Although space-based QKD tests have been carried out in other states, no dedicated quantum satellites comparable to the Chinese one in terms of functionality and performance are presently in service or under development. Technology-push policies and publicly funded infrastructural deployments have fostered the rise of a remarkable national industrial capability. There are several Chinese commercial vendors, and a patent analysis conducted by the JRC *(Figure 14.1)* shows that companies headquartered in China have filed more patent applications for QKD than any other.

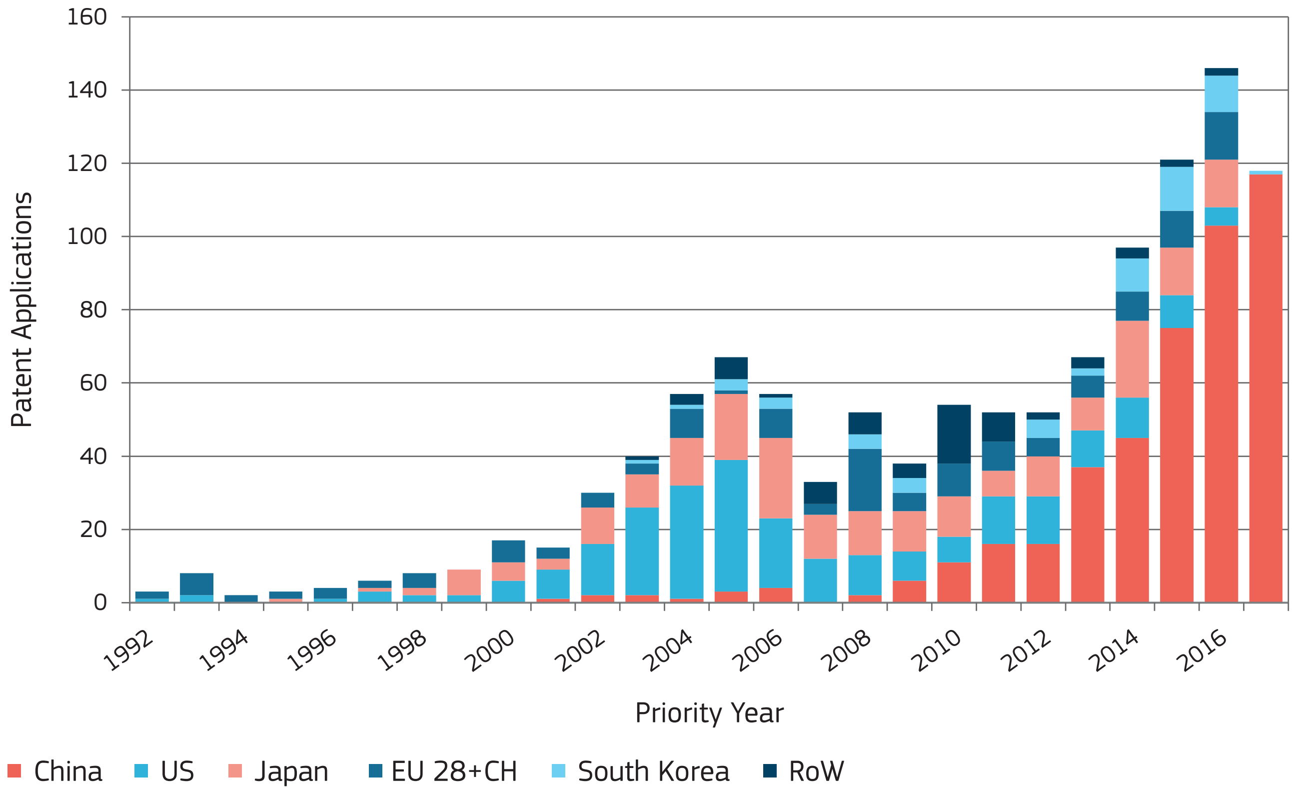


Figure 14.1: Patent applications in QKD - country of applicant's headquarters
Source: JRC computations

14.3. China is accelerating its efforts to catch up in quantum computing

Quantum computers are increasingly seen worldwide as a strategic technology, not only for their potential impact in scientific areas such as chemistry and material science, but also for their role in advancing artificial intelligence and for their crypto-analytical capabilities. Currently, the technological leading edge is held by large North American corporations *(Table 14.1)*. To fill the gap, China is building a National Laboratory for Quantum Information Science in Hefei, with the mission of 'ensuring the security of national information and increasing the computing power'. This received an initial investment of CNY 7 billion (≈ EUR 1 billion) (MOST, 2017). Quantum-enhanced machine learning has been included as a priority in the Next Generation Artificial Intelligence Development Plan. Some private companies are also investing: in March 2018, Alibaba and the Chinese Academy of Sciences announced they had 'launched the superconducting quantum computing cloud, featuring a quantum processor with 11 quantum bits of power' (Alibaba, 2018).

14.4. Applications with military and intelligence impact are being targeted

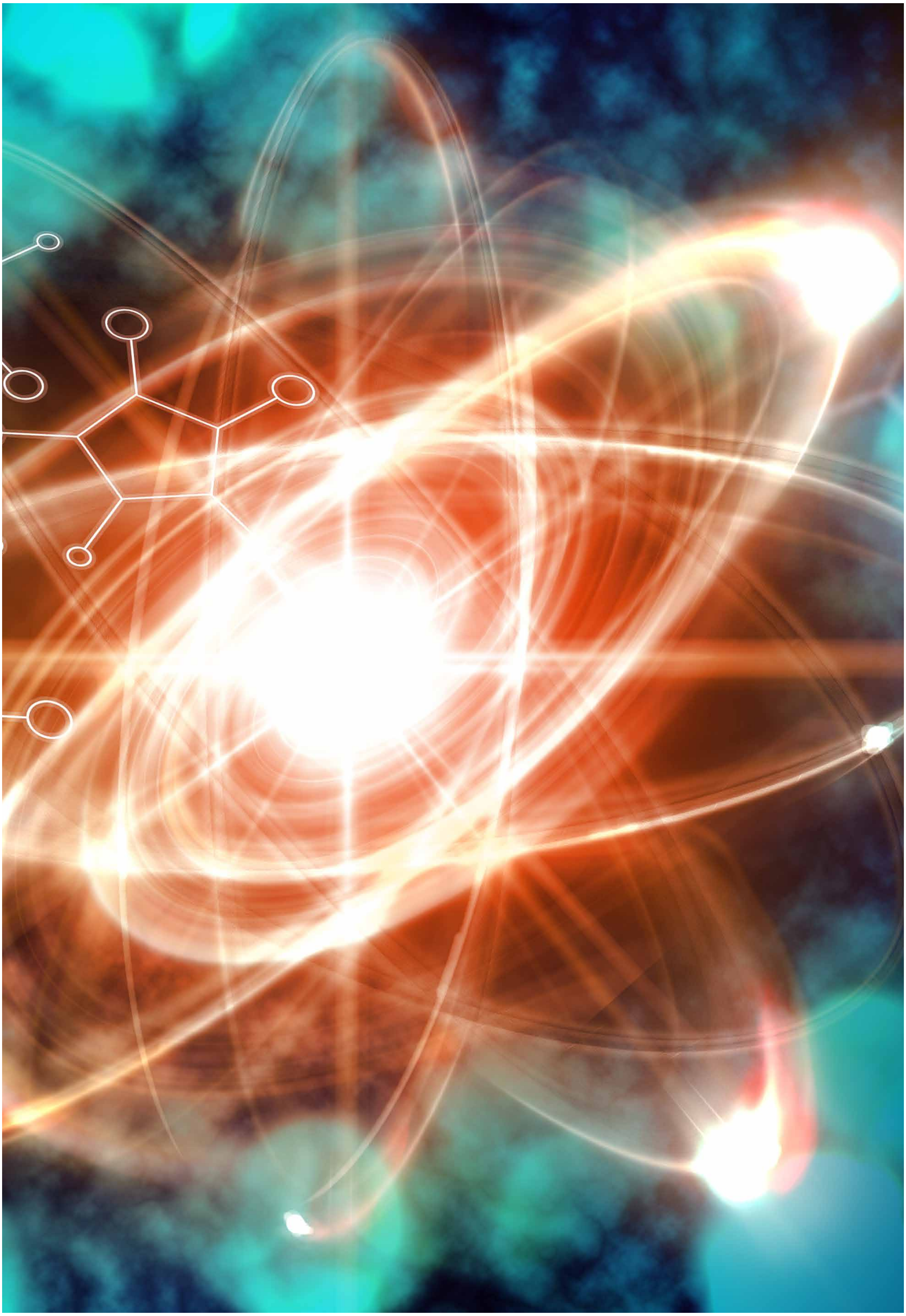
QTs can yield applications in autonomous navigation and faint-object detection. China has developed gyroscopes and accelerometers based on cold atom interferometry, and emphasised their use to increase the inertial navigation capabilities of submarines and missiles. A quantum radar prototype exploiting photon entanglement to detect hostile stealth aircraft has also received wide press coverage; several observers highlight however that the field performance of such a system may fall short of expectations, and its actual use is burdensome. Synergies with the space sector are actively being explored:

the Chinese Academy of Sciences is building an extremely sensitive quantum 'ghost imaging' device for use in future Chinese satellites. The Tiangong-2 space station was used to test a space-grade atomic clock based on cold atom technologies; such clocks could in future be employed by the Beidou Global Navigation Satellite System, to increase the precision of the positioning service. Support for quantum technologies suits the Chinese national strategy for military-civil fusion, which focuses on leveraging synergies between defence and commercial developments.

Company	Type	Technology	Physical qubits*	Next goal
Google / NASA, Universities Space Res. Ass. (USA)	Gate	Superconducting	72	N/A
IBM (USA)	Gate	Superconducting	50, 20 online	N/A
Intel (USA) / QuTech (NL)	Gate	Superconducting	49	N/A
Rigetti (USA)	Gate	Superconducting	19, 19 online	128
China Academy of Science / Alibaba (China)	Gate	Superconducting	20, 11 online	N/A
Chalmers University (Sweden)	Gate	Superconducting	N/A	≥100
Microsoft (USA) / Univ. California, QuTech (NL), Niels Bohr Inst. (DK), ETH (CH), University Sydney (AU),...	Gate	Topological	1	N/A
Innsbruck University (Austria)	Gate	Ion Trap	14	N/A
IonQ (USA)	Gate	Ion Trap	11	32
NQIT (UK)	Gate	Ion Trap	N/A	400
National Science Foundation STAQ Project (USA)	Gate	Ion Trap	N/A	≥64
Intel (USA) / QuTech (NL)	Gate	Spin	26	N/A
Silicon Quantum Computing Pty (Australia)	Gate	Spin	N/A	10
University of Wisconsin (USA)	Gate	Neutral Atoms	49	N/A
Harvard/MIT (USA)	Simulator	Rydberg Atoms	51	N/A
University of Maryland/NIST (USA)	Simulator	Ion Trap	53	N/A
D-Wave (Canada)	Annealer	Superconducting	2048	5000
IARPA QEO Research Program (USA)	Annealer	Superconducting	N/A	100

*:suitable metrics to gauge the performance of quantum computers are still being developed.

Table 14.1: Leading organisations and companies in quantum computing
Source: JRC computations



NUCLEAR ENERGY

15.1. China has become largely self-sufficient in reactor design and construction

Mainland China has over 40 nuclear power reactors in operation, about 20 under construction, and more about to enter construction. The government's long-term target, as outlined in its Energy Development Strategy Action Plan 2014-2020 (State Council, 2014), is for 58 gigawatt electrical (GWe) capacity by 2020, with a further 30 GWe under construction *(Figure 15.1)*. The impetus for nuclear power in China is increasingly due to air pollution from coal-fired plants.

China is now competing with Russia, Argentina and the US to commercialise small modular nuclear reactors

After building nuclear power plants based on foreign technology (notably, the first EPR and AP1000 reactors to become operational have been built in China), China has now become largely self-sufficient in reactor design and construction, as well as aspects of the fuel cycle. A major strength is the nuclear supply chain. While the fast reactors are part of China's own electricity generation policy, at least for now, the small modular reactors (SMRs) target the global markets more, following demonstration units built at home. Such demonstration projects include the high-temperature gas-cooled reactor pebble-bed module (HTR-PM), the ongoing construction of the first Chinese offshore (floating) nuclear power plant, and the development of new, small-scale nuclear reactor designs that could be used in isolated regions or for propulsion.

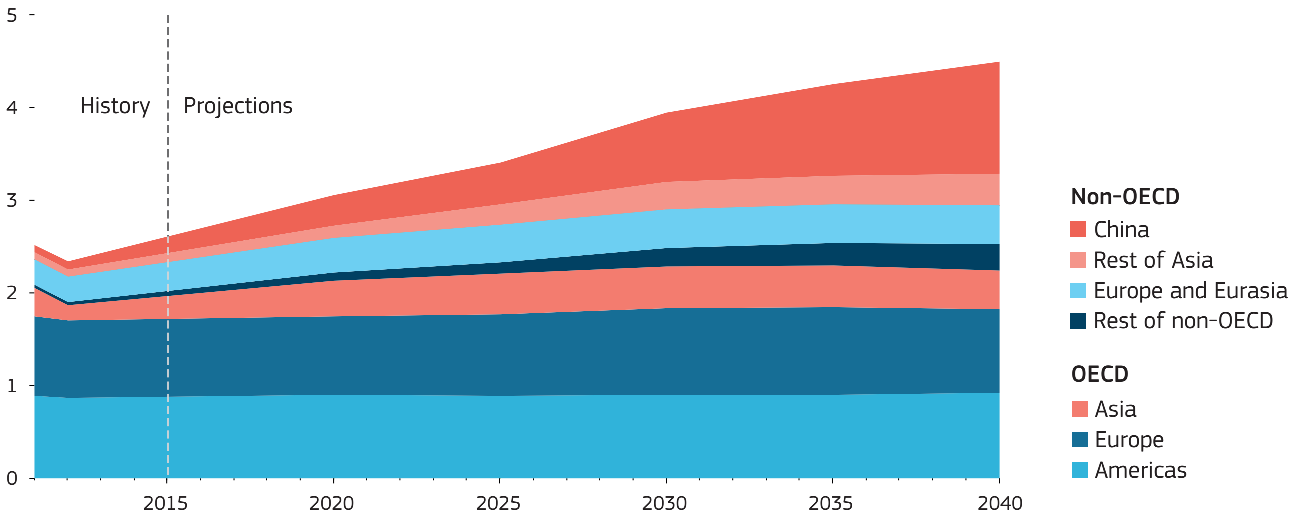


Figure 15.1: Nuclear electricity generation in China and other regions
Source: U.S. Energy Information Administration (2016)

15.2. China has improved its nuclear safety practices, but significant knowledge gaps remain

Since the establishment of its first nuclear power plant, China has shown unprecedented eagerness to achieve the world's best standards in nuclear safety and has learned a lot about the safety practices needed for nuclear power plants. There are still significant gaps and delays in know-how and deployment of effective processes, especially in domains not related to power plant operation and not flagged for technology export, such as spent fuel management. Both the Chinese safety regulator and the industry face a severe shortage of nuclear talent and competence to cope with the fast-paced expansion of nuclear technology applications.

China seems to be committed to improving its national nuclear security system and strengthening international nuclear security. Deploying more advanced technologies will increase its responsibilities and raise its profile in this area. For China to take on a global leadership role, it must go further than its current commitments, which are perceived outside China as minimalist and transactional.

15.3. China 'goes global' with exporting nuclear technology, including heavy components

The National Development and Reform Commission has established a policy of exporting nuclear technology, based on Chinese technological development, with Chinese intellectual property rights and backed by full fuel cycle capability. China is now competing with Russia, Argentina and the US to commercialise SMRs.

Codes and standards from several countries have been integrated into a new Chinese set of codes and standards. This will facilitate the export of Chinese nuclear power plants and their licensing. The strategy is to 'promote' Chinese technical standards to its customers to aid a nuclear push abroad. Besides safety and security issues, the implementation of nuclear power plants and more particularly modular reactors (e.g. SMRs, offshore-floating) in geopolitically sensitive regions may have international political impacts.

15.4. China intends to build strategic and commercial uranium stockpiles

In addition to the development of domestic production, the China National Nuclear Corporation (CNNC) is looking to increase investment in overseas uranium mining, to ensure fuel supply for the expected growth in its domestic nuclear power generation (Nucnet, 2018). Currently, in more than 12 countries, 71 nuclear reactors are under construction, 165 are planned, and 315 are proposed. China plans to spend USD 2.4 trillion to expand its nuclear power generation by 6 600 % (Bohlsen, 2018). As a consequence, some estimates indicate that the global uranium demand will rise by roughly 40 % by 2025. China must assess the extent to which and for how long it will trust global market forces to provide uranium. If the demand for uranium continues to grow, it is forecast that low supplies will cause shortfalls and that this will affect uranium price negotiations as early as 2019. To achieve sustainability, the combined developments of mineral exploration and of advanced fuel cycle technologies need to be replenishing resources at least as fast as they are consumed.

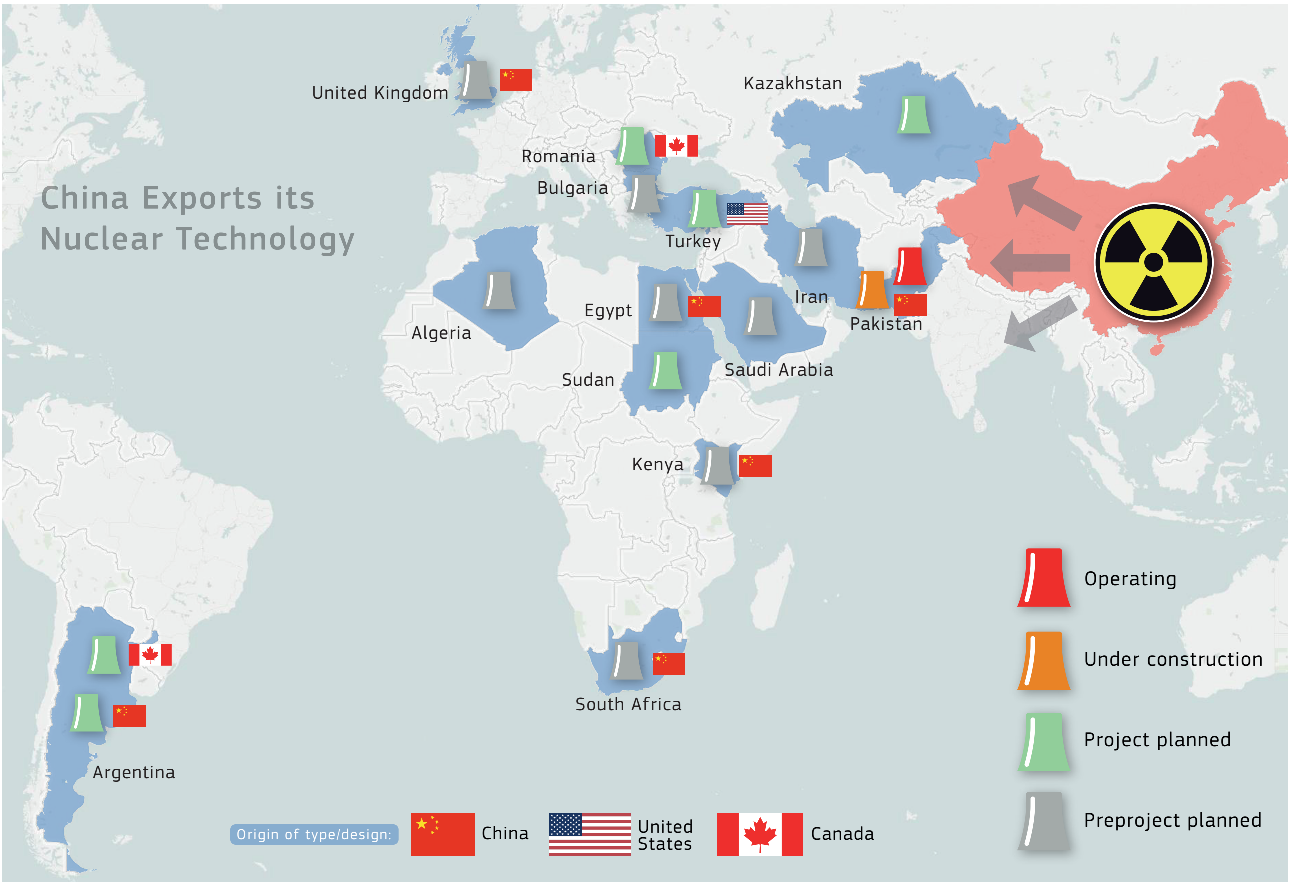


Figure 15.2: Nuclear projects with major Chinese participation
Source: The Mercator Institute for China Studies (MERICS), 2016

NEW ENERGY VEHICLES AND EQUIPMENT

16.1. China already has a 50 % share in the global market for new energy vehicles

China identifies the development of new energy vehicles (NEVs) as a strategic target in addressing the environmental and economic challenges of the transition to sustainability (World Bank, 2011). Over 20 years of policy supports (Kong, 2016) have resulted in China having a 50 % share of the global market *(Figure 16.1)* (CAAM, 2018). The Chinese market is expected to grow further and peak towards 2022 (Bloomberg NEF, 2018a), as policy targets have not been met and there is a further drive for improvements in infrastructure for new energy mobility, such as parking

China created a dominant new energy vehicles industry whilst imposing market restrictions to its domestic market for international firms

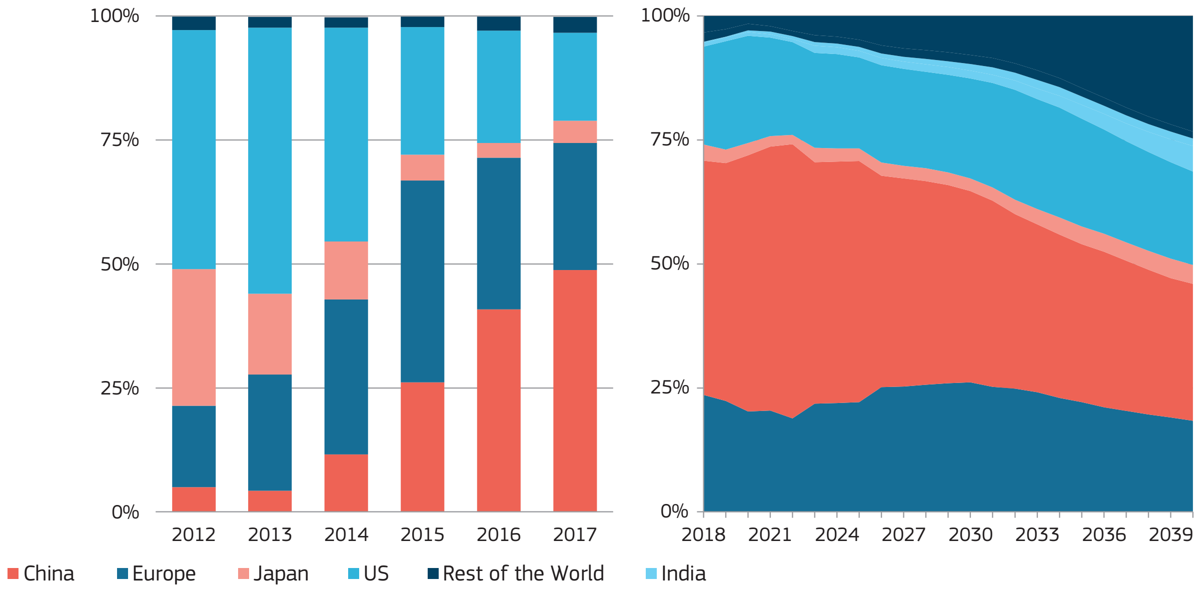


Figure 16.1: Global electric vehicle sales shares, %
Source: JRC based on CAAM (2018) and BloombergNEF (2018a)

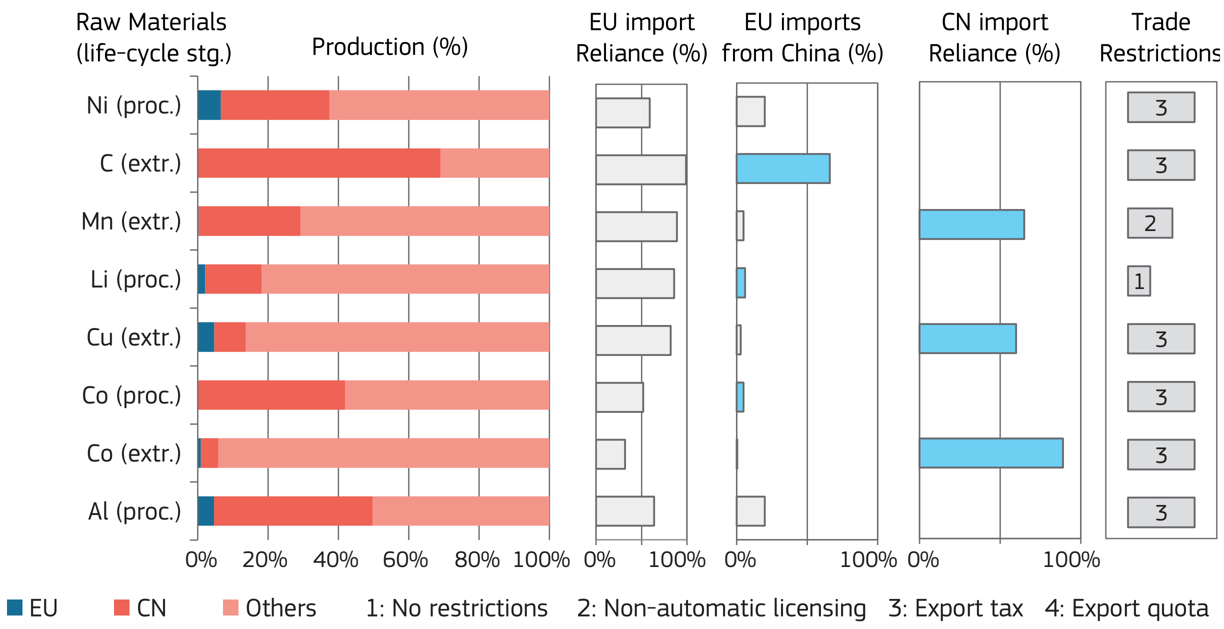


Figure 16.2: Raw materials for electric vehicle batteries
Source: JRC based on OECD (2014), EC (2017a,b), Gulley et al. (2018)

and charging stations and a push for vehicle fleet modernisation (NDRC, 2016). New requirements (minimum quotas) for the production of NEVs mean that automotive companies will have to ramp up their efforts to meet policy targets (Bloomberg, 2018).

Following the vision of MIC 2025, China created a dominant domestic industry, imposing market restrictions for international firms. Some of these (e.g. equity caps) are being lifted, but foreign firms are reluctant to change joint venture arrangements, seeing Chinese partners as a necessity to access subsidies and R&D support and also to circumvent rules that favour Chinese producers (ECC, 2018a). Since 2002, China has acquired EUR 0.6 billion in European, American and Asian assets in electric transport, energy storage and fuel cells, but has invested less than half as much in greenfield projects (including recent announcements, e.g. CATL in Erfurt). In contrast, EU investments in China are predominantly greenfield (exceeding EUR 3.5 billion) and only include one brownfield, minority-stake acquisition to the order of EUR 0.7 billion (Bloomberg NEF, 2018b; FDI Markets, 2018).

16.2. In the future, China is likely to control the global supply of raw materials for new energy vehicles

The Chinese electric vehicle market has driven up demand for raw materials. A large share of the production of these is concentrated in China, although China also relies on imports from third countries for over 60 % of the supply of cobalt, copper and manganese *(Figure 16.2)*. Based on the market projections for NEVs, current worldwide demand for these materials could increase 20 to 70 times by 2030 (Bloomberg NEF, 2018a; EC 2017a,b).

China's efforts to control the global supply of raw materials include trade restrictions and the acquisition of strategic assets (e.g. Sociedad Química y Minera of Chile) (OECD, 2014; Vidal-Legaz et al., 2016; Bloomberg NEF, 2018b). The EU is not self-sufficient in any of the relevant raw materials, and is highly dependent on imports. Nonetheless, with the exception of graphite, the share of European imports of these materials from China is relatively small *(Figure 16.2)*. The majority of manufacturers of battery anode and electrolyte materials are also based in China *(Figure 16.3)*, close to both resources and markets, where they benefit from lower production costs and less stringent environmental legislation (EC, 2018).

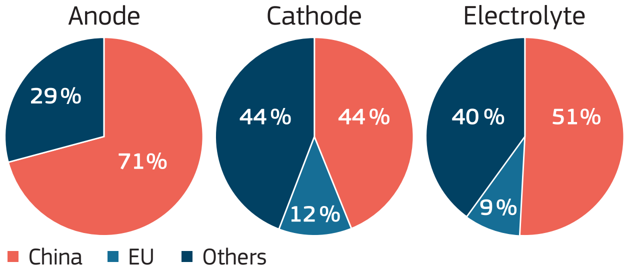


Figure 16.3: Li batteries' key components production
Source: JRC based on OECD (2014), EC (2017a,b), Gulley et al. (2018)

16.3. The Chinese government strongly supports innovation and industrial development of new energy vehicles

China's 13th Five-Year Plan to 2020 includes research priorities for NEV batteries: using advanced manufacturing technology to develop large-capacity long-life lithium titanate batteries, new high-efficiency technology, polymer thin film materials for high energy density batteries, and electrodes (NDRC, 2016). Annual public investment in low-carbon energy R&I in China is around EUR 4 billion, comparable to the respective public investment in EU Member States. The part dedicated to sustainable transport, which includes renewable fuels, batteries and emobility, is estimated to be in excess of EUR 1.5 billion, twice as much as the equivalent expenditure in the EU (JRC, 2018b).

Nonetheless, support for research projects has been much less intensive than purchase subsidies; as a result, Chinese NEVs and components have lacked consistency and quality (Zhang and Qin, 2018). In a cost-conscious internal market, advances come through incremental learning on production capabilities developed in China, through joint ventures, or by establishing R&D facilities abroad to train Chinese engineers (e.g. Shanghai Automotive Industry Corporation's purchase of UK capabilities) (Watson et al., 2015). There has been a huge increase in domestic patents filed in China, driven by government incentives and tax breaks in support of filing patents and rewards for patents approved. However, the majority of these do not go on to file for international protection. In the period 2010-2014, les s than 2 % of Chinese inventions in batteries and e-mobility were protected in other countries, and could thus be considered high-value. In contrast, more than a quarter of worldwide high-value inventions in the same field were protected in China, making the Chinese market the second most targeted after the US *(Figure 16.4)* (JRC, 2018b).

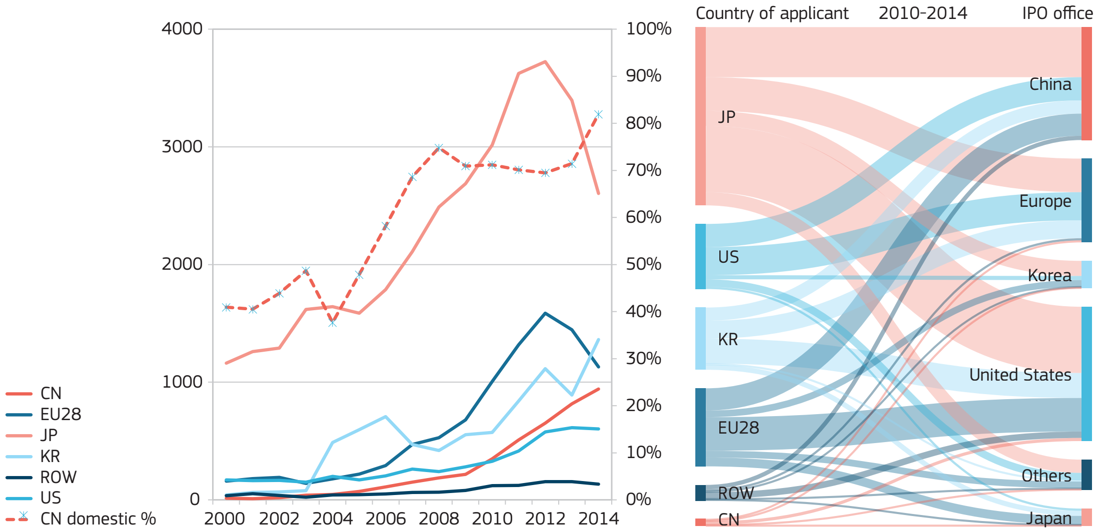


Figure 16.4: Patent families and flow of high-value inventions in batteries and e-mobility protected in five major patent offices (2010-2014)
Source: JRC (2018) based on EPO (2018), Fiorini et al, (2017)

WIND ENERGY EQUIPMENT

17.1. China leads in installed wind power

China's ambitious industrial and climate targets are closely connected with the future development of its wind sector. The country leads the world in wind energy deployment, with an installed capacity of 188 GW (EU: 178 GW; US: 89 GW). The main support instrument has been a feed-in tariff (2009) that rewarded production of renewable energy. This has recently been replaced by an auction system (GWEC, 2017; Bloomberg NEF, 2018c). The domestic wind industry has also been supported in a variety of ways; as a direct support, 2008 import tariffs on key components were refunded to domestic companies (Ni 2008). In 2012, China was accused of price dumping for wind towers for export, to increase its market share in foreign markets by driving out competition. Consequently, the US imposed 14-26 % import duties on China (Reuters, 2012).

> Despite the technological leadership of European wind equipment manufacturers, their market share in China has decreased

17.2. China is an exclusive producer of important rare earths

These policies, and the broad deployment of wind energy equipment (WEE) in China and worldwide, will put additional pressure on the supply of certain raw materials. These include rare earths (neodymium, praseodymium and dysprosium) and boron, embedded in the permanent magnet of direct drive and geared turbines, a vast array of materials used in steel production, plus aluminium, copper and lead. China is an exclusive producer of important rare earths, and is also responsible for at least 30 % of global production of other relevant raw materials, some of which are considered critical for Europe. Europe is heavily reliant on imports for the supply of relevant materials, with China accounting for 40 % of rare earths imported into the EU. A large proportion of the production of material composites for wind power equipment is also bound to Chinese industries. China produces 54 % of permanent magnets, 83 % of magnet alloys, and 45 % of carbon fibre composites *(Figure 17.1)*. These are key material composites for wind turbines (Blagoeva et al., 2016).

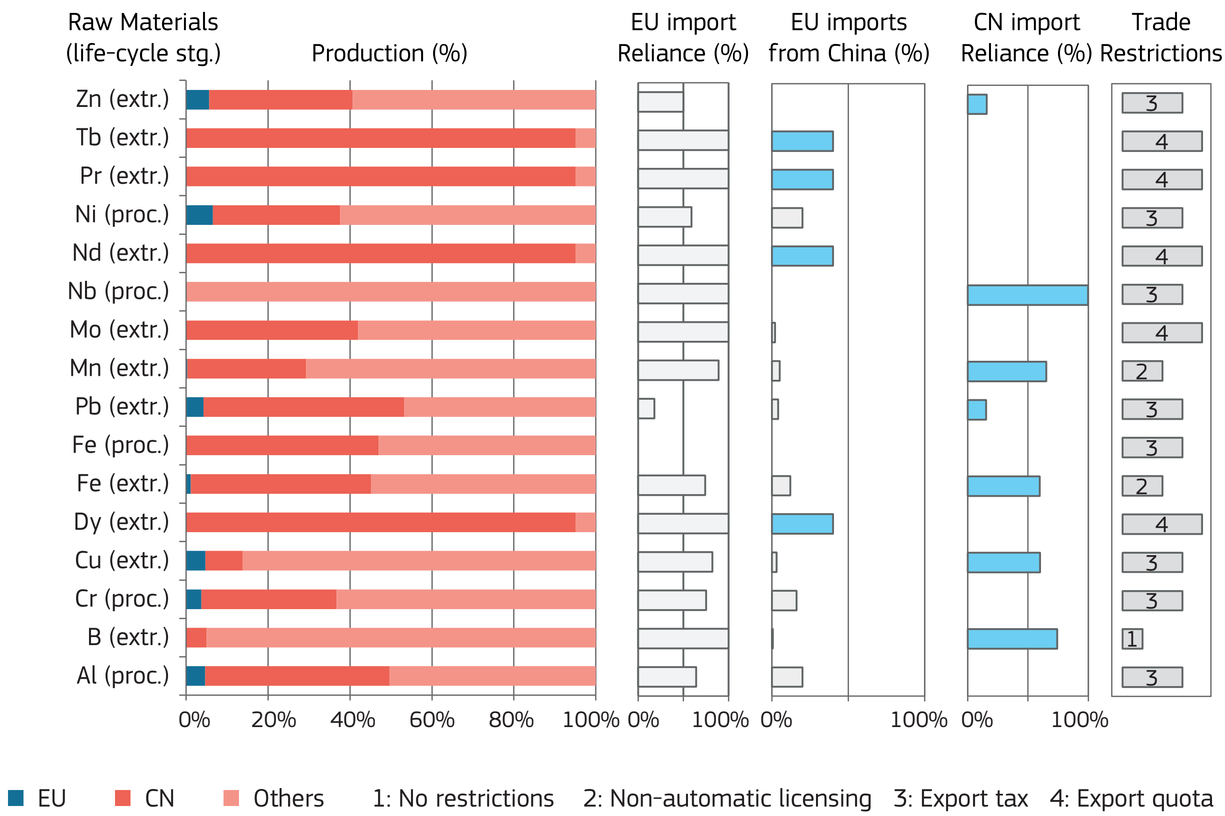


Figure 17.1: Market statistics of raw materials contained in wind turbines

Source: JRC based on OECD (2014), EC (2017a, b), Gulley et al. (2018)

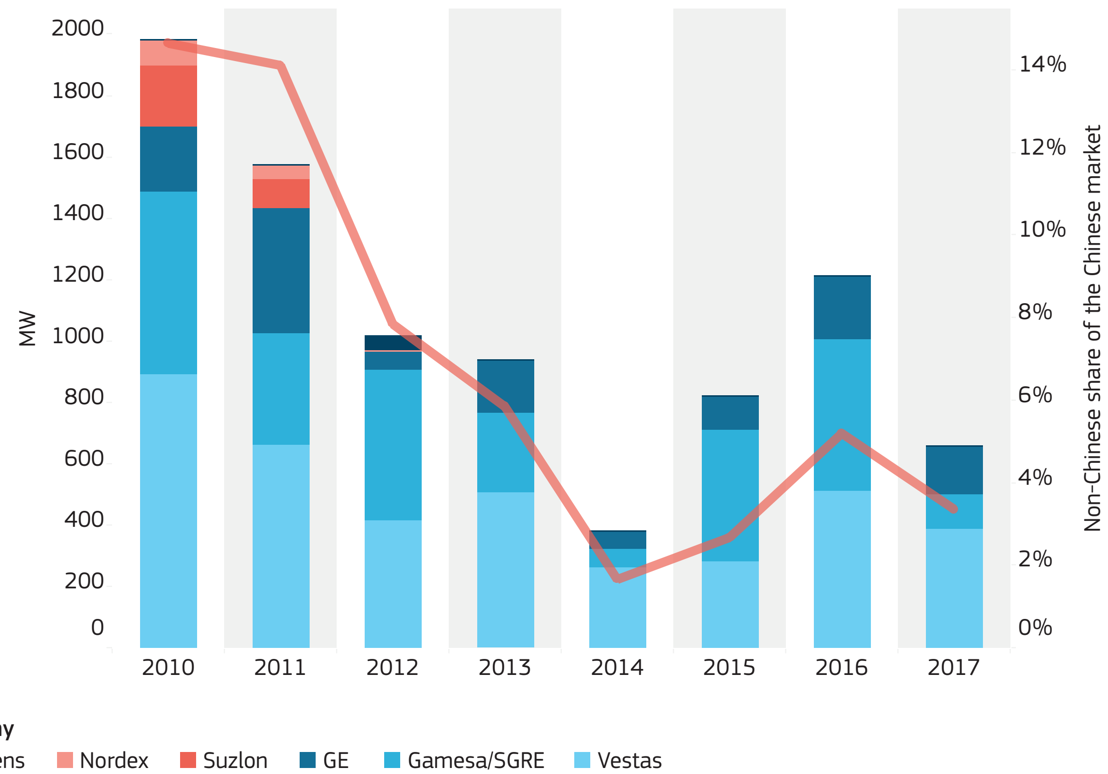


Figure 17.2: Market shares of foreign manufacturers

Source: JRC (2018)

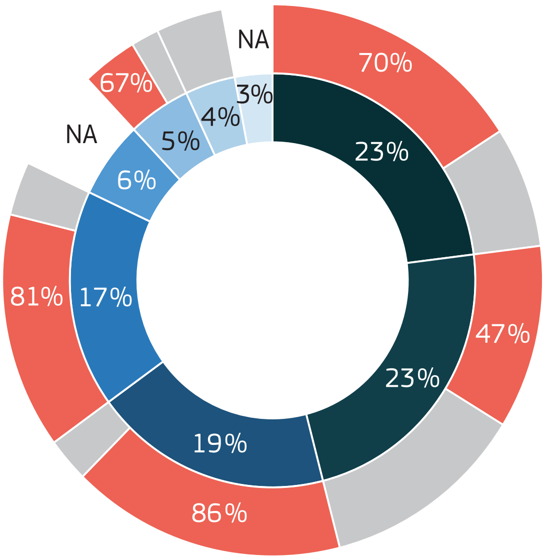


Figure 17.3: Chinese manufacturing (outer graph) compared to the CapEx by component (inner graph)
Source: JRC based on Moné at al. (2017) (2018)

17.3. A restricted market for foreign manufacturers

Chinese manufacturers are strongly consolidated in their home market, only allowing foreign manufacturers a penetration below 5 % of the new wind capacity installed in recent years, down from over 15 % in 2010.

This drop follows failing (Harbin Electric and General Electric) or struggling (Shanghai Electric Wind Energy and Siemens) joint ventures with Chinese state-backed companies, caused by the aggressive capacity expansion of local firms, which focus on short-term market share gains but lack product quality (SCMP, 2014). The substantial investment in manufacturing capabilities also reflects the strong domestic consolidation *(Figure 17.3)*. China is estimated to have invested around EUR 32 billion in manufacturing facilities of wind turbine components, representing around 65 % of the total investments in manufacturing facilities worldwide. The spotlight of the Chinese manufacturers is focused on high-cost wind turbine components (towers and blades) and those widely used by other industrial sectors (generators and gearboxes).

17.4. Climate and environment – strong drivers for wind energy equipment research & innovation

China's substantial private and public R&I investments reflect a clear commitment towards a green shift and stimulating innovations in wind energy. China's 13th Five-Year Plan to 2020 includes research priorities in: demonstration of ultra-large offshore wind turbines; carbon fibre composites for blades; intelligent offshore wind turbines; and key technologies for flexible DC transmission. China already ranks among the leading countries in publications on strategic wind energy components, and is very active n patent filings *(Figure 17.4)*. As in the case of other technologies, the latter are mostly filed in the domestic office, with a very small number registered or granted by foreign patent offices. A quarter of high-value wind energy inventions are protected in China, making this the second most targeted market. More than half of these patents are filed by European applicants.

The above is consistent with China's strategy to attain a strong position in low-carbon energy technologies as described in *Chapter 9*, by first gaining control of the internal market with low-priced products and subsequently acquiring know-how and capacity to compete at the international level.

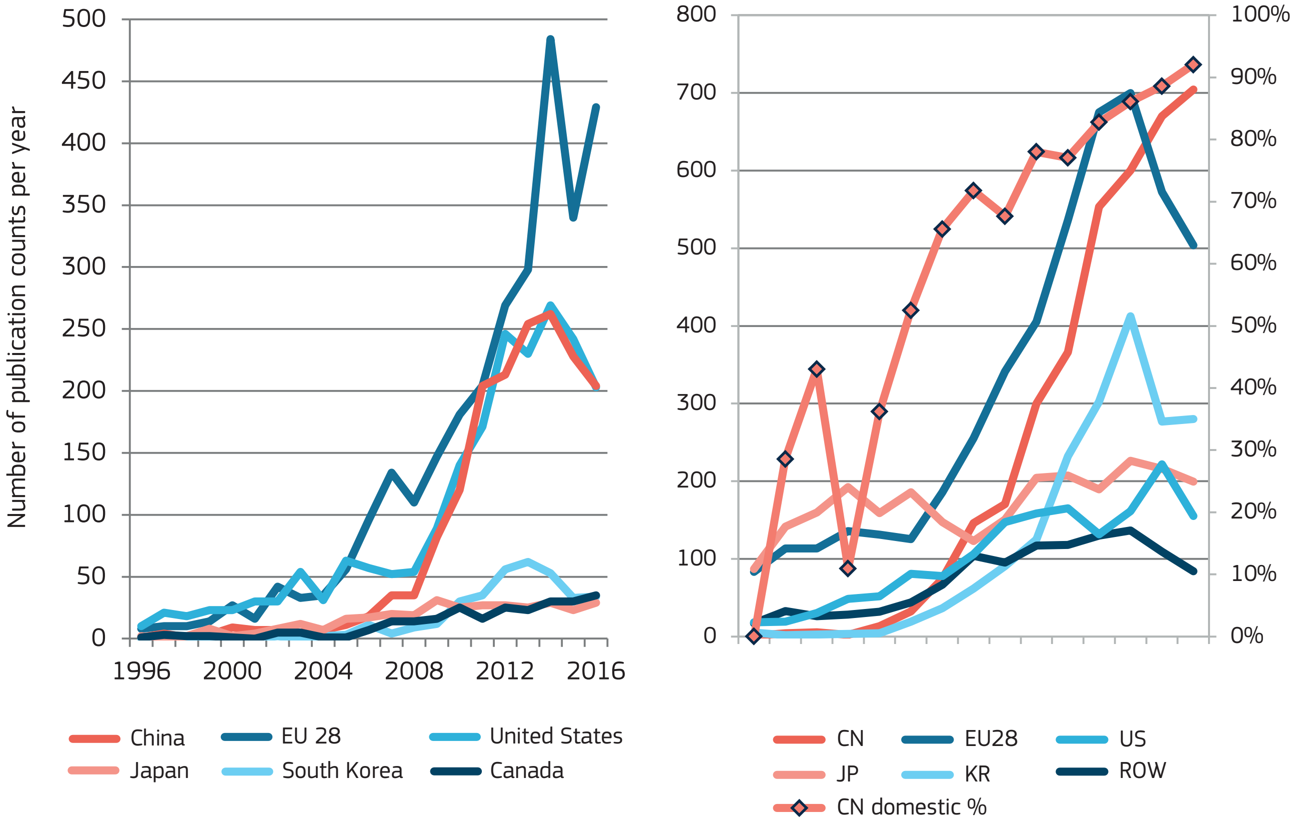
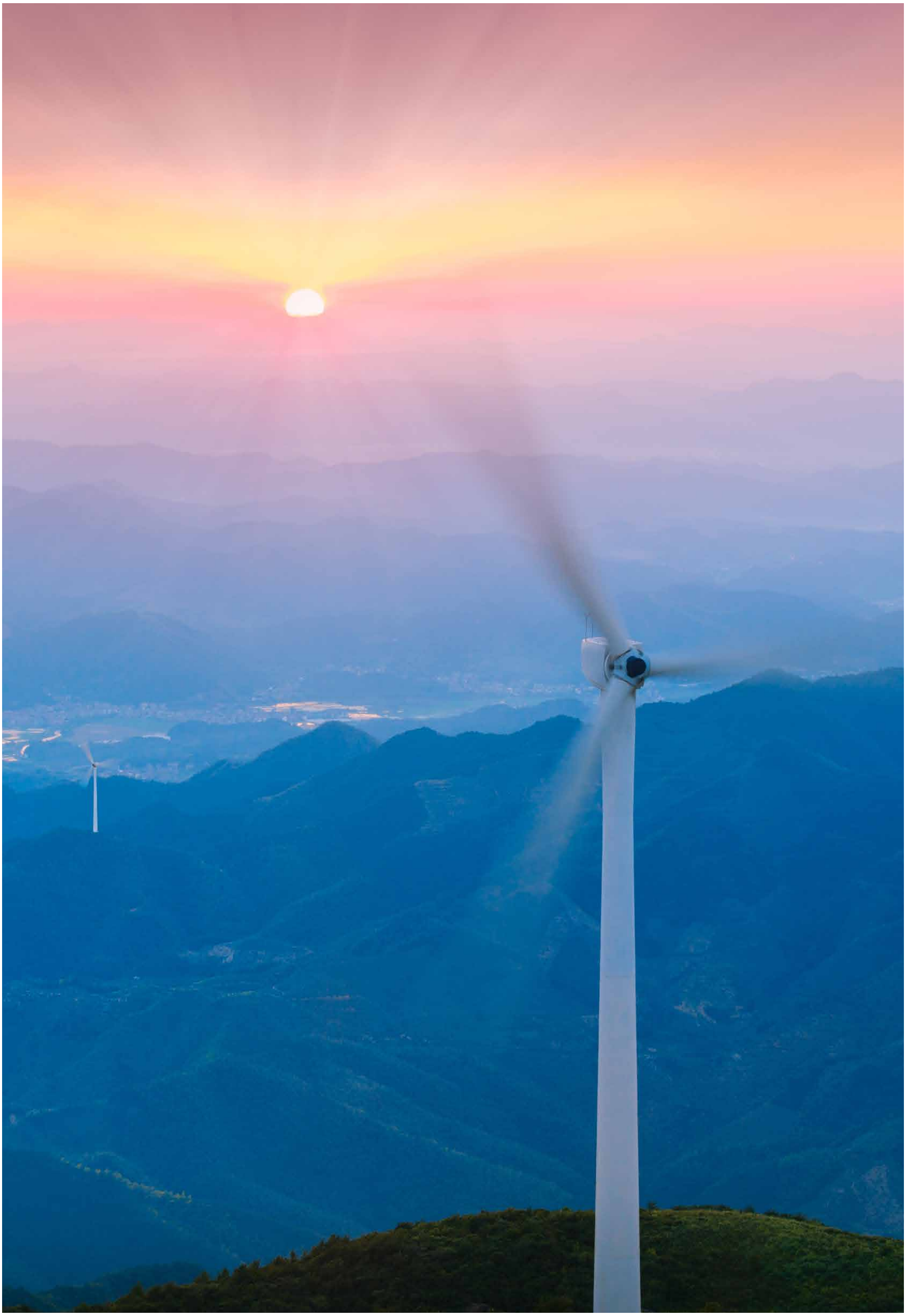


Figure 17.4: Leading countries in publication activity on blades (left) and international comparison of inventions in wind energy (right)
Source: Telsnig et al. (2018) , JRC (2018) based on EPO (2018), Fiorini et al, (2017)



SOLAR PHOTOVOLTAICS

18.1. China has been the largest manufacturer of solar cells and modules since 2007

In 2005, the Outline of the National Medium- and Long-term Plan for science & technology Development (2006–2020) first listed solar photovoltaics as a priority theme. Since the 11th Five-Year Plan (2006–2010), investments in the Chinese solar industry have been considered of strategic interest. The rapid growth of the Chinese photovoltaic (PV) industry, and the first PV crisis in 2011/12, resulted in an industrial restructuring and upgrading plan (2011-2015)

State subsidies may have played a decisive role in helping Chinese industry achieve global leadership in solar photovoltaics

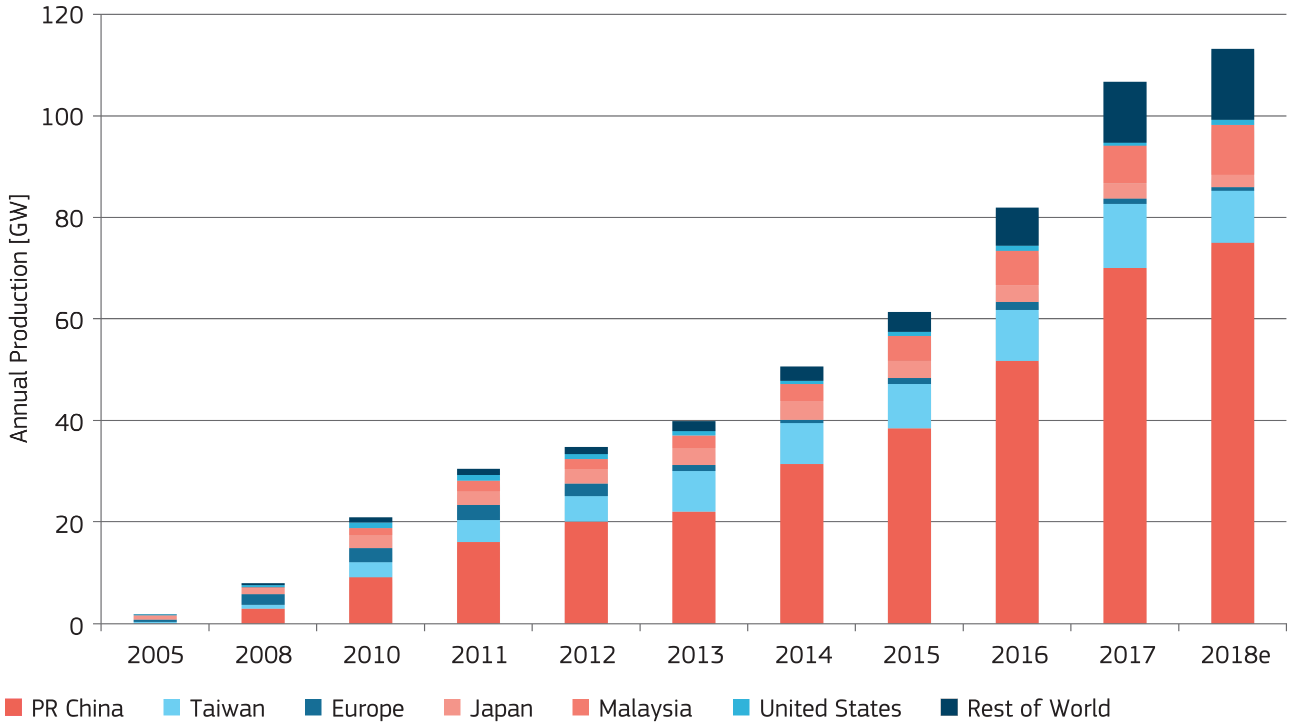


Figure 18.1: World PV solar cell production from 2005 to 2018 (estimate)
Source: Photon (2012) PV News (2015) and JRC PV Status Reports (2018) 2002- 2018

for the PV industry by the Chinese Ministry of Industry and Information Technology. Key to the plan was that by 2015 only 'backbone' enterprises with a minimum production of 50 000 tonnes of polysilicon, or 5 GW of solar cell or module production, should continue to be supported.

Production of solar PV devices has increased ore than fivefold over the past decade. China has become the leader in PV manufacturing and use *(Figure 18.1)*[31]. In 2017, the number of Chinese manufacturing companies ranking among the top 10 was as follows: polysilicon – six; solar cells and solar modules – eight each, solar inverters – four (51 % market share). Chinese companies are no longer only manufacturing in China, but have manufacturing sites in over 20 countries. Europe still has a sizable manufacturing industry for PV equipment, but the number of Chinese competitors, as well as their investment in European companies, is growing rapidly.

18.2. China overtook the EU in terms of total installed photovoltaic power capacity in 2017

With annual installations of 53 GW, China reached a total installed capacity for solar PV of 135 GW at the end of 2017, representing 33 % of the worldwide installed capacity of 408 GW *(Figure 18.2;* Systèmes Solaires, 2018). About 14.4 GW were through residential PV systems, and 36.6 GW through utility-scale systems. In 2017, electricity production from PV systems was 118 TWh, or 1.9 % of total electricity demand. Just in the first 6 months of 2018, more than 24 GW were connected to the grid. The International Energy Agency expects over 200 GW of new PV capacity to be added between 2018 and 2023, which would increase the total capacity to 340 GW (IEA, 2018).

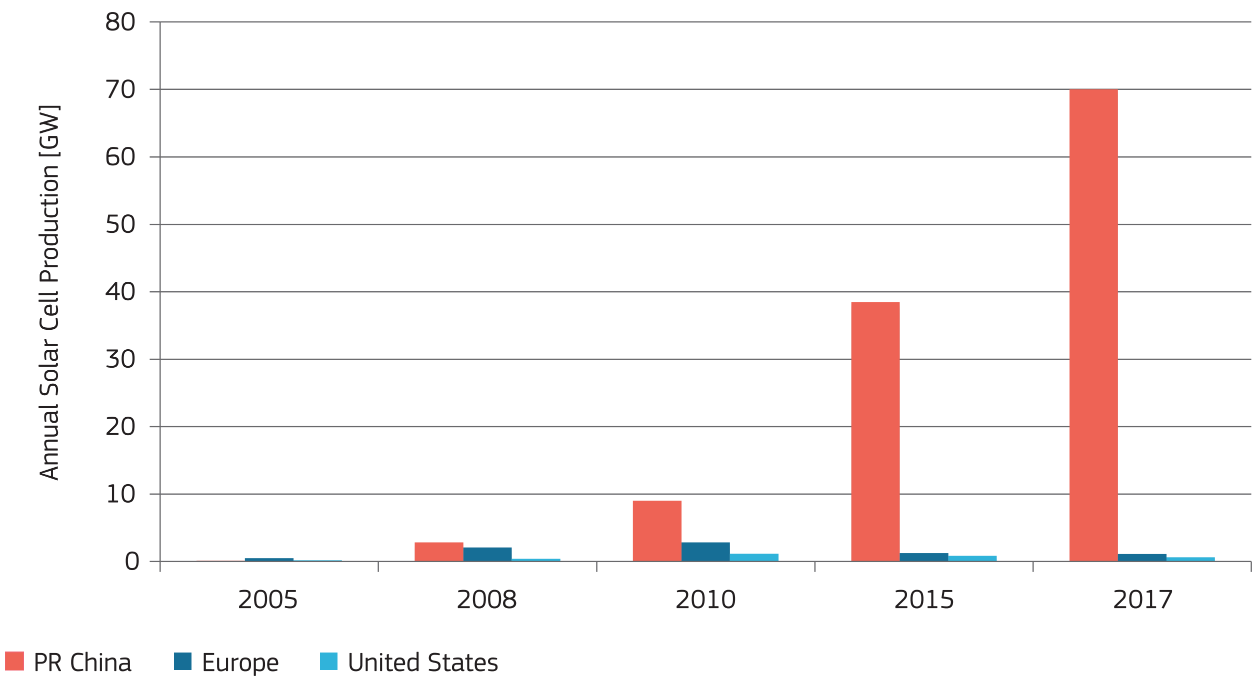


Figure 18.2: Cumulative PV installations from 2010 to 2018 (estimate)
Source: EurObserv'ER , IEA (2017), Solar Power Europe (2018) & JRC PV Status reports 2002 - 2018

According to the 13th Five-Year Plan (2016-2020) adopted on 16 March 2016, China intends to continue to cut its carbon footprint and become more energy-efficient. The share of non-fossil energy should increase from 12 % in 2015 to at least 15 % by 2020. Further targets are 18 % lower carbon dioxide emissions and 15 % less energy consumption per unit of GDP in 2020, compared to 2015. This Plan includes expected investments of around EUR 309 billion in non-fossil power[32], and of around EUR 349 billion for the upgrade of the grid infrastructure, CNY 1.7 trillion of which is intended for the distribution network (Caixin, 2015; Wang, 2016).

China is the largest producer along most of the value chain for established PV systems (polysilicon, solar cells and modules, power inverters, and manufacturing equipment). Manufacturing and engineering jobs in these areas are primarily focused in China. Of course, Europe still maintains the local installation and maintenance jobs related to PV deployment in Europe, which provide more than half of the jobs.

One of the fastest growing companies is Tongwei Solar *(http://www.tw-solar.com/en),* part of the Tongwei Group, a private company with core business in agriculture and new energy, set up only 5 years ago in 2013.

In 2011, Tongwei Group signed an integrated PV strategic cooperation agreement with Xinjiang Government, which included a 50 000-tonne solar-grade polysilicon project, a 3 GW solar wafer and solar cell project, as well as five solar power plants.

In 2017, Tongwei reported an annual production capacity of 20 000 tonnes of polysilicon, 5.4 GW for solar cells and 350 MW for solar modules. The company is working to increase its capacity to 50 000 tonnes of polysilicon and 10.4 GW solar cells by the end of 2018.

With a polysilicon production of about 17 000 tonnes and solar cell shipments of 3.85 GW, the company already ranked sixth for both products in 2017 (Systèmes Solaires, 2018).

China's photovoltaic industry and trade policy

On 8 November 2012, the European Commission initiated an anti-subsidy proceeding with regard to imports into the EU of crystalline silicon PV modules and key components (i.e. cells and wafers) originating in China. The EU imposed anti-dumping and anti-subsidy measures between December 2013 and September 2018. As a counter measure, China's Ministry of Commerce (Mofcom) introduced anti-dumping and anti-subsidy duties on polysilicon imports from the EU from May 2014 onwards. On 31 May 2018, China's National Development and Reform Commission (NDRC), the Ministry of Finance and the National Energy Administration (NEA) issued a common statement announcing the end of feed-in tariffs for new utility-scale solar projects and the intention to use competitive bidding in the future. The timing of this announcement was a surprise for most in the solar industry. However, the phase-out of the feed-in scheme was not completely unexpected as the NEA had, in March 2018, released a draft for comments of the Renewable Portfolio Standard and Assessment Methods that would create a market for renewable energy certificates (RECs). At the end of September 2018, a second draft was released for comments, with an updated target of at least 35 % renewable power by 2030. The final document was expected to be published before the end of 2018.

CHINA IS ON TRACK TO ACHIEVE GLOBAL INDUSTRIAL LEADERSHIP IN KEY SECTORS

19.1. China is undergoing horizontal structural change to attain global leadership in new industries

MIC 2025 aims to establish a long-term structural change process, resulting in higher productivity, increased competitiveness, moving up global value chains and the reallocation of labour across sectors. Evaluating the effectiveness of China's efforts requires a cross-cutting perspective across the sectors identified by the MIC 2025 strategy. *Table 19.1* presents a horizontal analysis of key indicators discussed in the preceding chapters.

The largest gains in Chinese competitiveness are in ICT, Electrical, Machinery and Rail industries

Indicator	ICT	Mach.	Mat.	Electrical	Rail	Aero	Pharma	Medical
Competitiveness (GVC; RCA)	+ +	+	-	+ +	+	- -	- -	-
FDI (M&As)	+ +	+ +	x	x	- -	-	- -	- -
Venture Capital	+	n.a.	+	n.a.	n.a.	n.a.	+	+ +
BERD	x	x	-	x	n.a.	n.a.	+ +	+ +
Investment Conditions	- -	+	+	n.a .	n.a.	X	- -	- -

Table 19.1: Horizontal Analysis of the Chinese Industry
Source: JRC

The selected indicators (global value chains, revealed comparative advantage, Foreign Direct Investment and mergers and acquisitions, venture capital investments, BERD and foreign investment conditions) capture some of the most representative features of China's modernisation process and they range across selected MIC 2025 strategic sectors.

China's performance in terms of these indicators has been assessed on the basis of the material presented in the preceding chapters *(Table 19.1)*. *Table 19.2* provides the taxonomy applied to a broadly comparable classification of sectors and fields across indicators. The indices (GVC, RCA, FDI, VC, BERD and protectionist business conditions for foreign firms) are not available with the same classifications for all industries.

Table 19.2 therefore proposes an allocation in order to associate the MIC 2025 priorities to the indicators used. The '+ +' sign in the table indicates a sector performing more than 1.5 times better than the average level of all other sectors considered. A '+' sign indicates a performance for this sector that is between 10 % and 50 % better

Indicators	Competitiveness (GVC; RCA)	FDI (M&As)	Venture Capital	BERD	Investment Conditions
ICT	Computer, electronic and optical products (GVC);	Next generation IT	Information technology	Computer, electronic & optical	IT and telecoms (BCS)
Machinery	Machinery (GVC)	Numerical control machinery & robotics	n.a.	Machinery & equip. n.e.c.	Machinery (BCS)
Materials	Basic Metals, Minerals, Wood (GVC)	New materials	n.a.	Leather, Wood, Chemical raw materials, Chemical fibres, Ferrous metals, Non-ferrous metals	Metals, minerals and other machinery (OECD)
Electrical	Electrical (GVC)	Electrical equipment	n.a.	Electrical equip.	n.a.
Rail	Rail Vehicles (RCA)	Advanced rail equipment	n.a.	Railway equipment, ships, aerospace	n.a.
Aero	Aeronautics (RCA)	Aerospace and aviation equipment	n.a.	Railway equipment, ships, aerospace	Aerospace and aviation (BCS)
Pharmaceuticals	Pharma (GVC)	Biopharmaceuticals & HT medical devices	Biopharmaceuticals	Pharmaceuticals	Pharma (BCS)
Medical	(Electronic) Medical instruments (RCA)	Biopharmaceuticals & HT medical devices	Medical Devices and Equipment	Medicines	Medical devices (BCS)

Table 19.2: Taxonomy of the Chinese Industry
Source: JRC

than the sectoral average. The '- -' and '-' signs indicate an underperformance of a certain sector more than 50 % or between 10 % and 50 % below the sectoral average respectively. An 'X' stands for a performance that is close to China's sectoral average performance. This is therefore not assumed to significantly affect China's position. For some sectors insufficient data was available, in which case an 'n.a.' sign is included in *Table 19.1*.

To assess the international competitiveness of Chinese industry, *Table 19.1* considers participation in manufacturing global value chains (GVCs) and revealed comparative advantage in exports (RCA). One can observe a particularly strong performance in the ICT and electrical component sectors, while China also performs well in the railways, machinery and materials sectors. In the pharma, medical equipment and aerospace sectors the performance is relatively poor.
To account for the strategic planning of overseas investments, *Table 19.1* considers the percentage of Chinese deals in the EU (M&As) by sector of the target investment. Again, a very strong performance of the ICT as well as the machinery sectors can be observed. Materials and electrical equipment also perform well though their relative performance is slightly weaker. Foreign investments in railways, aerospace, pharma and medical equipment-related sectors perform less well than the sectoral average.
The amount of VC deals from China towards the EU reflects a potential alternative approach to acquiring technology and knowledge from abroad. Here one observes sizeable investments in the medical equipment and pharma sectors as well as above average investments in ICT and materials.

Sectoral Business Expenditures in R&D (BERD) data can be used to show which sectors are contributing most to the rapid growth in Chinese R&D intensity. Most sectors for which data are available perform at a similar level to the sectoral average. However, one can see particularly large investments in pharma and medical equipment, which may indicate an effort to make up for China's relatively weak knowledge position in these fields compared to the US and the EU (see also *Tables 19.3* and *19.4)*.

Comparing the level of unfavourable treatment and restrictiveness to the other selected indicators allows for a preliminary assessment of the impact of protectionist conditions on the performance of Chinese companies. The unequal treatment of foreign companies appears to have contributed considerably to the competitiveness of domestic industry in strategic sectors such as ICT.

The largest gains in competitiveness are thus displayed in the MIC 2025 priority areas ICT, electrical, machinery and rail industries *(Table 19.1)*. The increase in competitiveness in the ICT, electrical and machinery sectors is aligned with the trends in M&As, and at least for ICT the same applies for VC flows. BERD however does not increase more in these sectors relative to the others studied. There is, for example, strong growth in BERD in the pharmaceutical and medical sector, which also receives substantial amounts of VC. Investment conditions are particularly adverse to foreign ICT companies, hence domestic firms have seen large gains in competitiveness. Business conditions for foreign firms appear relatively fair in machinery and materials, while China's industry has shown a relative loss in competitiveness for these sectors. The pharmaceutical and medical sector also presents investment conditions that strongly favour domestic companies. However, this sector scores very low on competitiveness. It is not supported by strategic M&As, though VC investments are high. This suggests that restrictive foreign investment conditions alone are not enough to determine international success. As shown in Table 19.3, China's domestic knowledge of the life sciences and biotechnology which underpin this high-tech sector remain weak relative to the US and the EU. As the ICT sector profile illustrates, China's strong performance in some sectors appears to stem from a combination of strategic FDI and VC investments coupled with investments in R&D, while exploiting protective investment conditions.

These considerations are particularly relevant in the context of the regulations and framework conditions set by the Chinese government.
In many of the sectors studied, improvements in competitiveness appear to be due to the actions and policies of the Chinese government.
This can be illustrated by the Chinese approach to meeting the national demand for wind energy equipment. To promote the dominance of domestic firms, the government provided national firms with refunds of import tariffs on key components in addition to implementing public procurement rules that hinder foreign competition. From this secure domestic base, Chinese firms can now improve their export competitiveness.

19.2. Chinese patents and scientific specialisation converge with the EU in natural and computer science but diverge in other areas

Tables 19.3 and Table 19.4 respectively present a comparison of the Revealed Technological Advantage (RTA) and Revealed Scientific Advantage (RSA) of China in relation to the EU for several fields. The latter have been ordered along similar categories available for both indicators and all remaining categories have been rearranged around the closest counterparts.

The two tables show China's RTA and RSA percentage change variations with respect to the scores for the EU where "+ +" describes an increase of above 80 % vis-à-vis the EU while "+" refers to a rise between 20 % and 80 %. "- -" and "-" follow the same rationale for negative values. "X" stands for a change within 20 % which is considered not high enough to significantly affect China's position.

Scientific specialisation in China is focused on the natural, computer and material sciences *(Chapter 9)*. The EU on the other hand has a more widespread scientific profile with comparative strengths in the life and social sciences. RTA (patents) and RSA (publications) scores relative to the EU appear to be aligned around positive values for sectors related to ICT and negative ones for pharmaceuticals, biology and bio-technology. Interestingly, there are a number of misalignments such as for materials, chemical engineering and chemistry, environmental technology and ecology which all display a negative RTA and a positive RSA. China's RSA and RTA in life science fields and biotechnology are, in general, relatively weak. As shown in *Chapter 11*, there are niches, such as genomics as well as plant molecular biology, in which China's performance is stronger. Overall, the RTA and RSA comparison confirms the need for China to broaden its science & technology capabilities to fulfil the MIC 2025 priorities to become a leader in the high-tech sectors targeted *(Chapter 9)*.

Technological Fields	RTA
Computer technology	+ +
IT methods for management	-
Audio-visual technology	+ +
Telecommunications	+
Digital communication	+
Basic communication processes	-
Medical technology / Clinical medicine	- -
Pharmaceuticals, Pharmacology & Toxicology	- -
Analysis of biological materials	- -
Biotechnology	- -
Food chemistry	- -
Organic fine chemistry	- -
Chemical engineering / Chemistry	-
Electrical machinery, apparatus, energy	-
Semiconductors	+ +
Optics	+ +
Environmental technology, ecology	-
Materials	-
Macromolecular chemistry, polymers	- -
Basic materials chemistry	-
Surface technology, coating	x
Micro-structural and nano-technology	x
Handling	-
Machine tools	-
Engines, pumps, turbines	-
Textile and paper machines	-
Other special machines	- -
Thermal processes and apparatus	- -
Mechanical elements	-
Transport	-
Furniture, games	- -
Other consumer goods	- -
Civil engineering	-
Measurement	-
Control	-

Scientific Fields	RSA
Computer technology	+
IT methods for management	x
Medical technology/ Clinical medicine	-
Pharmaceuticals, Pharmacology & Toxicology	x
Immunology	-
Microbiology	-
Neuroscience & Behavior	-
Biology & Biochemistry	x
Molecular Biology & Genetics	x
Psychiatry/Psychology	- -
Agricultural Sciences	x
Plant & Animal Science	-
Chemical engineering / Chemistry	+ +
Environmental technology, ecology	x
Materials	+ +
Engineering	+
Mathematics	+
Physics	+
Geosciences	x
Space Science	-
Economics & Business	-
Social Sciences, general	- -

Tables 19.3 & 19.4: China's RTA & RSA comparaison vis-à-vis the EU
Source: JRC elaboration on PATSTAT and Web of Science data

19.3. Chinese export and technological competitiveness move hand in hand

China's growing technological strength is evident from the increasing R&D expenditure in high- and medium-high-tech sectors as well as the growing numbers of patent applications. China's export competitiveness is improving in many sectors, in some through the help of government regulations and tools such as mandatory joint ventures or investment restrictions.

A focus on selected technological competences as well as the traditional advantage in relatively cheap labour form the basis for China's growth in innovation performance and export competitiveness. The relative specialisation in net exports and technology[33] respectively is similar.

The degree of specialisation is comparable in pharmaceuticals, communications, broadcasting engineering, computers, optical and measurement technologies as well as electronics and rail vehicles *(Figure 19.1)*.

19.4. Expanding industries with the highest all-encompassing gains for the whole ecosystem

Chapters 11 to 18 show how Chinese efforts are devoted to promoting industries with high all-encompassing potential effects on the whole country and its economy. For example, the progress in artificial intelligence and robotics is complementary to both manufacturing and production in virtually all other sectors. Quantum technologies provide cutting-edge

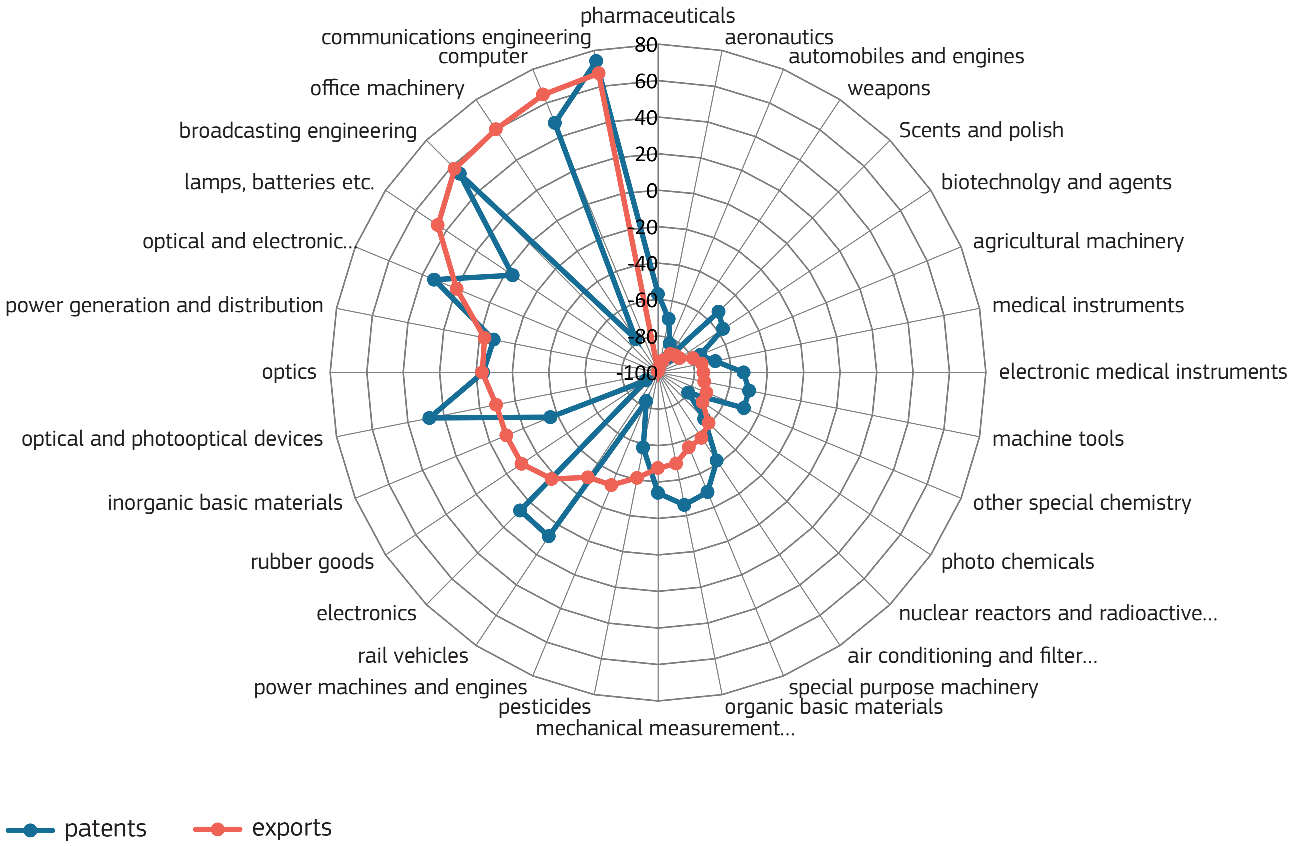


Figure 19.1: China's RSA (2013-15) and RCA (2014-2016)
Source: EPO - PATSTAT; UN - COMTRADE; Frietsch's Computations based on Neuhäusler et al. (2018)

improvements to the overarching need for better, faster and more secure computation and communication processes. New energy vehicles (NEVs), solar and wind energy equipment, beyond supporting a more environmentally friendly production system, are at the core of China's energy transition to achieve energy independence by reducing reliance on oil imports. The Chinese government is strongly promoting technological developments with the highest market potential and key strategic applications.

This horizontal analysis of China's sectoral industrial performance shows that at present China's largest gains in competitiveness are in ICT-related fields, partially as a result of Foreign Direct Investment conditions that have favoured domestic companies. As shown by the health and pharma sectors, however, protecting local firms through FDI conditions alone may be insufficient for driving international success.
A competitive domestic knowledge base is also important and China will need to broaden its R&D portfolio in order to meet its 2025 targets.
China's improved performance appears to stem from a specific and advantageous combination of productivity-enhancing investments and transfer of technology from foreign sources while exploiting sheltering framework conditions.

ENDNOTES

1 National Development and Reform Commission (NDRC) through the Internet Plus strategy; Ministry of Science an Technology through the National Technology Plan.

2 Two further funds provide unclear amounts of financing. These are: Major Technology Equipment Insurance Compensation System (loans to support high-tech industry product development) and Sichuan Made in China 2025 and Innovation-Driven Project Guiding Fund (funding for R&D in several sectors, including graphene and nine other areas).

3 Computed by the JRC on the basis of the World Input Output Database (WIOD) *www.wiod.org*. The 2016 release provides a time-series of world input-output tables covering 43 countries –including all EU Member States – and 56 economic activities over the period of 2000 to 2014. For further details on the computations, see JRC (2018).

4 Note that the contributions from 'demand factors' and 'competitiveness' may not always add up to the total shown, due to the presence of ambiguous interaction terms.

5 Note that the contributions from 'demand factors' and 'competitiveness' may not always add up to the total shown, due to the presence of ambiguous interaction terms.

6 A description of the methodology used in this chapter can be found in Arto et al. (2015).

7 This reduction was mainly driven by finance and by medium-tech manufacturing sectors.

8 The revealed comparative advantage index of net exports (Balassa and Nolund, 1989) is calculated by dividing each country's net exports (exports minus imports) of a specific industry by the total sum of the exports and imports of that industry. This formulation allows for the possibility of simultaneous exports and imports in relation to a particular commodity or industry. In the absence of imports, the index is equal to +1; in the absence of exports, it yields -1; and when exports and imports match the index is 0 by definition. As a consequence, this index ranges across (-1, +1).

9 In 2015, China produced or assembled about 28 % of the world's automobiles, 41 % of the world's ships, over 80 % of the world's computers, over 90 % of the world's mobile phones, 60 % of the world's colour TV sets, over 50 % of the world's refrigerators and 80 % of the world's air conditioners, 24 % of the world's power, and 50 % of the world's steel (source: China Manufacturing 2025, European Chamber of Commerce, 2017, Section 2).

10 By affecting the market structure, M&As can increase industry concentration and reduce competition, despite creating the base for competition over appropriability of transferable technology.

11 Results may be biased towards companies with higher tangible / intangible asset ratios if intangibles are not correctly reported or omitted from companies' balance sheets.

12 The graph presents the shares of the major world regions in the amount raised by VC-backed companies, in USD billion, between 2010 and 2017.

13 The Venture Source database covers seven categories of sector: i) business & financial services, ii) consumer goods group, iii) consumer services group, iv) energy & utilities group, v) healthcare group, vi) industrial goods & materials group, vii) information and technology group. These sectors were aggregated into five categories of sector (information technology; business, consumer and retail; healthcare; energy; and materials).

14 The groups are: Industrial and Commercial Bank of China Ltd. (ICBC), China Construction Bank Corporation (CCB), Agricultural Bank of China Ltd. (AgBank), Bank of China Ltd. (BOC), China Development Bank (CDB), Bank of Communications Co., Ltd. (BoComm), Postal Savings Bank of China Co., Ltd. (PSBC). Data for PBSC is not available before 2010. The variation is computed as total assets in 2017 over those in 2010, minus one.

15 This dynamic must be viewed in the context of China's dangerous debt mountain and the necessity to diversify banks' balance sheets full of non-performing loans. Corporate debt was estimated at 175 % of the country's GDP in 2017, up from around 100 % just over a decade ago.

16 Data are not available for European countries alone. China has reported data to the Bank of International Settlements (BIS) for international banking statistics only since Quarter 4 of 2015, whereas most OECD countries have reported these data since the early 1990s and with greater level of detail (e.g. specifying the counterparty country).

17 Source data is Locational Banking Statistics from BIS. This dataset accounts for the unconsolidated volume of banking investment including those transactions with branches, subsidiaries or joint ventures. *https://www.bis.org/statistics/bankstatsguide_repreqloc.pdf* (last accessed May 2019)

18 While syndicated lending is only a fraction of banks' total lending, in the absence of other credit information and sometimes even aggregated data (as is the case for China) it is commonly used to measure bank lending policies and their effects in the corporate sector.

19 The loan deal included commitments from a dozen banks, with Citigroup Inc. acting as the coordinator.

20 The syndicated loans made to foreign companies between 2000 and 2018 (about 10 000 deals) were aggregated and the amount assigned to the bank's parent company, as is usually done in the literature (Sufi, A., 'Information asymmetry and financing arrangements: Evidence from syndicated loans', *Journal of Finance,* 62, pp. 629–668, 2007). Loans for which the amount of the loan or the industry code are not available were excluded.

21 The broad framework conditions cover, among other things, access to finance, access to human capital, access to knowledge and other factors that influence the performance of firms in the innovation system. This chapter focuses on the regulatory framework in China, while the chapters on Chinese Industrial Strategy 2025, China's R&I Strategy and performance and Internationalisation of China's R&I system deal with these aspects of the innovation system respectively.

22 While following OECD definitions, GERD and BERD figures are believed to be inflated (Frietsch, *forthcoming).*

23 This graph shows only transnational patents targeting international markets. The growth in SIPO patents is many times higher, but it is often questioned whether this rapid growth in SIPO patents is an accurate reflection of China's growing technological capabilities (Frietsch, *forthcoming).*

24 See annex 1 for an organigramme of China's R&I governance

25 Figure 10.4 assigns authors to a country on the basis of their 'first authorship' and addresses used in subsequent publications. The US and EU authors in China comprise many returnees who started their research careers in the US and the EU respectively

26 Personal communication Professor Max von Zedtwitz, Director of GLORAD.

27 Note: EU firms: 111 823 patents at EPO (154 520 at USPTO); US firms: 49 624 patents at EPO (110 662 at USP TO) and China-based firms: 2 283 patents at EPO (5 578 at USPTO).

28 Calculations were done according to the Technology Innovation Monitoring tool (TIM) developed by JRC. This tool uses SCOPUS and PATSTAT as bases for the searches (until July 2017). Patent data are a combination of applications in all patent offices including SIPO.

29 All companies, research institutes or organisations, from the data sources considered, displaying R&D, industrial or market activities identifiable as related to AI.

30 Please note that Alcatel-Lucent has since been acquired by Nokia.

31 Solar cell production refers only to cells in the case of wafer silicon-based solar cells; complete integrated module for thin films. Only those companies which actually produce the active circuit (solar cell) are counted whereas those purchasing circuits and make solar modules are not counted.

32 Exchange rate at September 2016: EUR 1.0 = CNY 7.45

33 Revealed Technology Advantage (RTA) sets the share of a technology in a country in relation to the share of that technology worldwide. To ease interpretation, the respective shares are on a logarithmic scale and multiplied by 100.

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LIST OF TABLES AND FIGURES

ACKNOWLEDGEMENTS

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We are grateful to Cong CAO, Melisande CARDONA, Claudio FEIJOO, Florian FLACHENECKER, Rainer FRIETSCH, David KLENERT, Montserrat LOPEZ COBO, Niels MEYER, Nicolae SCARLAT, Sofia SAMOILI for the background documents they prepared and the insights, comments and support they shared throughout the development of this report.

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KJ-NA-29737-EN-N

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ISBN 978-92-76-02997-7
doi:10.2760/445820