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White Paper

Fostering the European Innovation System

Management summary

This paper compares the innovation systems of the U.S., China and the EU 27 on a national scale with the ultimate goal of proposing measures that foster innovation in Europe. For each peer group member, key performance indicators (KPIs) within the areas of fundamental research, commercialization and scaling will be compared. Furthermore, the general structure and major traits of the peer group member's research and innovation landscape are discussed. As Germany holds a leading position in terms of research within the EU 27, major deviations in KPIs between Germany and Europe will be highlighted in addition.

While the U.S. innovation system is notably based on a powerful role of private investors and corporates, the Chinese innovation system is characterized by a high degree of governmental steering. The European innovation system, on the other hand, shows a high variety of funding options on both a European level as well as for the individual member states.

Five major challenges of the European innovation system arise from comparing and analyzing the peer group members:

- The high variety of public sources for research funding in the European Union leads to a high complexity and significant coordination efforts.
- Compared to the U.S. and China, European funding of fundamental research is increasingly falling behind in both relative and total spendings.
- Especially when compared to the U.S., Europe shows lower average volumes and numbers of private investments, implying a lack of funding throughout the stages of commercialization.
- European funding is characterized by increased risk-aversion. This holds true for both public and private funding.
- Strict and diverse regulation might decelerate or even impede innovation along the entire value chain, that reaches from research to industrialization.

To address these challenges, four recommendations for action are proposed:

- Expand public funding for fundamental research at European level.
- Increase the share and priority of risk-based funding.
- Establish a regulatory environment that fosters innovation.
- Create stronger incentives for domestic founding and settlement.

To sustainably foster economic growth and maintain its competitiveness in the long term, it is crucial for Europe to adapt governmental innovation processes in a timely manner.

Motivation and fundamentals

Innovation is a vital part of global advancement. Through developing new solutions to pressing challenges or improving the overall quality of life, innovation is an essential catalyst for economic growth. From a macroeconomic perspective, innovation not only increases efficiency, but also fosters national resilience and an economically sustainable development. [1–3] To stand strong in the face of innovation giants like the U.S. and China, the smaller European nations must strategically collaborate to overcome the structural disadvantage of market fragmentation through embracing openness and connectedness [4]. Such additional challenges for Europe intensify the demand for a well-functioning innovation system. To enable a better understanding of the paper's contents, the major terms used in this context are defined in the following.

An innovation system is a network of actors, institutions and processes that contribute to the development and introduction of new innovations. It includes both formal and informal structures and networks that support innovations all the way from exploration to commercialization. Innovation systems can be considered on different levels (e.g., national, regional, company-specific). In the context of this paper, it is limited to national innovation systems, comprising six actors in total. The first entity are governments. On the one hand they act as an overarching source of public funding in fundamental research. On the other hand, they are responsible for establishing a seamless fiscal and legal environment that fosters innovation. The capital from governmental funds is primarily used by research institutions to perform research activities, thus creating intellectual property. Most research institutions are linked to universities and research societies, acting in public interest.

To create value from inventions, startups are a crucial vehicle. They capture the market through creating new products and business models and by finding a proper market fit. However, they need sufficient capital to successfully commercialize their inventions. Investors are the major public funding source for startups during the phase of commercialization. Apart from capital, investors provide professional guidance and access to their network in exchange for shares and steering rights within the company. Through (partially) acquiring startups, corporations can act as investors themselves (e.g., via corporate venture capital). However, they also perform research and development in their own facilities, helping them maintain and expand their competitiveness. Regardless of their decision to make or buy, corporations integrate and commercialize inventions. To connect corporations or investors with startups, facilitators play a major role. Apart from their strong network, they provide space for startups to work in (e.g., incubators) and help them growing their business through mentoring. [5]

An innovation landscape describes the distribution of innovation activities within an innovation system. It is characterized by the number and types of actors within the innovation system as well as their relations.

The "value chain" of an innovation can be subdivided into four stages. Initially starting with the discovery phase, where the focus lies on fundamental technology research. Major players involved are governments, acting as public funding bodies, and research institutions, performing the actual research activities. Stage two lies in technology development through startups, where the initial business model is defined, and the technology is validated via prototypes. The subsequent phase three is referred to as the "valley of death", in which market focused product and business development take place. Technological development is complete, and the invention can be pushed to the market. However, sufficient funding to tackle the market is required. This stage involves public investors and corporations as major funding sources as well as startups aiming to commercialize their inventions. The final stage is the industrialization, comprising the start of production and market launch. With funding secured and an initial market success, startups tend to scale and optimize their business. [6]

Comparison of national innovation systems

Methodology

To compare the innovation systems of the U.S., China and EU 27, this paper examines both quantitative indicators as well as the qualitative traits of the economy's research and innovation landscapes. Initially, the quantitative part covers KPIs that represent various stages along the value chain of an innovation. Indicators from the discovery phase should reflect the economy's capability to invent, while KPIs from subsequent stages should represent the economy's ability to successfully commercialize and scale these inventions. While strong invention capabilities and volumes are crucial to remain competitive, successful commercialization and industrialization are required to ultimately unlock the monetary benefits. Publicly accessible databases are used as sources for the quantitative comparison. Subsequently, the qualitative analysis covers the major traits of the research and innovation landscapes. Differences in governmental funding of research and development (R&D) are highlighted, as these lay the foundation for successful invention. Additionally, the economy's efforts towards commercialization are covered.

Quantitative analysis of KPIs on discovery and industrialization

This section covers the quantitative analysis of KPIs that reflect both the peers invention capabilities as well as their capabilities to commercialize and scale inventions. Two breakdowns per chapter are used to compare the peers.

Comparison of invention capabilities

The following section covers both inputs and outputs for R&D of fundamentals amongst the innovation systems. Efforts made in the form of financial investments in R&D are considered a major representative of inputs, indicating the importance of R&D to the economy. Furthermore, the systems outputs are compared by looking at the impact of scientific publications.

For the period of 2000 to 2020, the increasing importance of investing into R&D to economies across the entire peer group is displayed in Figure 1. For this purpose, both the development of absolute R&D expenditure in USD billions (left) and the R&D expenditure as a percentage of gross domestic product (GDP) (right) are illustrated.

While absolute R&D spending in the U.S. (CAGR +3.1%) and the EU 27 (CAGR +2.6%) increased only slightly over the period considered (2000 to 2020), China (CAGR +14.2%) is progressively converging with the U.S. total [7]. Parts of the strong growth in absolute R&D spending can be explained by the fact that China, at a CAGR of +13.4%, globally had the steepest growth in GDP throughout the period examined [8]. Additionally, China recorded the strongest growth in relative R&D expenditure during this period when compared to the other peers (CAGR +5.1%), which contributed to their growth in absolute expenditure. Looking at 2020, however, China's relative expenditure on R&D (2.4%) remains significantly lower compared to Germany (3.1%) and the U.S. (3.5%). Though, it is higher than the relative expenditure of the EU 27 seen holistically (2.2%). [7] Looking at the past development of relative expenditure on R&D, the figures for 2020 seem to be relatively unaffected by the COVID-19 pandemic. An isolated consideration of the development in total and relative R&D spending shows that China's global relevance in identifying fundamental research findings is apparently increasing, while the importance of the European Union seems to decline.

To further investigate the assumption formulated above, Figure 2 illustrates the impact of scientific publications. Based on the total number of citable documents and the number of citations, the average impact is derived as the number of citations per citable document. Said impact of scientific publications provides an initial impression for the quality of research in the respective economies, however it should not be seen too authoritative. The ratio was chosen due to its straightforwardness, as established indicators such as the h-index are harder to comprehend and interpret. The peers are examined for both the total period from 1996 to 2021 (left) and for the year of 2021 (right), thus comparing the long-term average to the current state.

With an average of 33.4 citations per document between 1996 and 2021, the U.S. tops the ranking, followed by the EU 27 (25.4). In the period considered, China (11.9) lies far behind. However, when looking solely at the year of 2021, China is positioned only slightly behind the U.S. (1.3) and the EU 27 (1.4) with an average of 1.0 citations per document. [9] This suggests that Chinese research is gaining in international relevance.

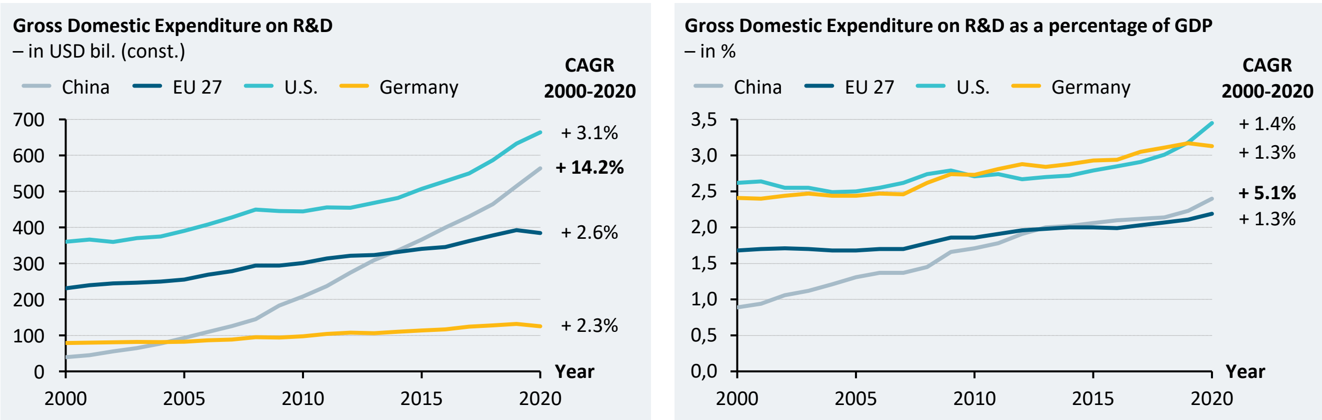

Figure 1: (Relative) gross domestic expenditure on R&D between 2000-2020 [7].

Scientific publications and citations
– between 1996-2021

	U.S.	China	EU 27
Number of citable documents – in tsd.	12,663	8,081	16,215
Number of citations – in tsd.	422,381	96,129	412,209
Average number of citations per citable document	33.4	11.9	25.4

Scientific publications and citations
– in 2021

	U.S.	China	EU 27
Number of citable documents – in tsd.	649	841	1,036
Number of citations – in tsd.	844	846	1,459
Average number of citations per citable document	1.3	1.0	1.4

Figure 2: Scientific publications and citations. Long-term average (1996-2021) vs. current state (2021) [9].

Comparison of commercialization and scaling capabilities

For innovation to have an impact on economic growth, an invention needs to successfully pass the stages of technology development, valley of death and industrialization, or simplified, the phases of commercialization and scaling [6, 10]. To protect their intellectual property, actors within the innovation system tend to patent their findings or inventions. Successful patenting can be seen as a prerequisite for entering the phase of commercialization and is thus analyzed in the first part of this section. Once inventions have entered the phase of industrialization, scaling is crucial to create actual value. As an indicator for the economy's success in scaling, startups with a major economic impact (valuation of at least USD 1 billion) are considered as relevant within the second part of this chapter.

Starting with the protection of intellectual property, Figure 3 shows the quantitative output of the innovation systems and provides an indication on quality of the according output across the peer group. The number of patents granted by the World Intellectual Property Organization (WIPO) is compared to the number of patent applications submitted to WIPO in 2021. In addition, the number of patents granted is set in relation to the number of employees in the respective economy. Due to differences in the labor force per economy, a relative indicator is crucial to ensure comparability.

With a total of 1.5 million patent applications filed in 2021, China substantially exceeds both the U.S. (0.5 million) and EU 27 (0.4 million). With a CAGR of +13.4% throughout the period of 2011 to 2021, China's volume in patent applications grew significantly stronger than the peers' (U.S.: CAGR 1.5%; EU 27: CAGR 0.4%). [11] However, China's steep growth in patent application filings is not solely the result of their growing innovation capacity. Experts suspect additional parameters to have a significant positive effect on the application count. For instance, growth in application numbers is spurred by various patent subsidy policies, that are promoted by the Chinese government. [13] By seeking for subsidization and increases in reputation, the number of patent applications grows [14], while their quality is falling behind. This is reflected in China's share of patents granted, when compared to other peers. While the EU 27 and the U.S. were granted roughly 60% of patents by WIPO, China's rate lies around 42% [11]. When comparing the number of patents granted to the economy's employee count (in thousands), the U.S. leads the peer group (1.8), followed by the EU 27 (1.2) and China (0.8). With 2.2 patents granted per thousand employees, the strong position of Germany is striking, being considerably ahead of the U.S. [11, 12]. Due to the high share as well as the (relative) number of patents granted, a substantial output of significant quality can be concluded for the German innovation system.

To compare the success in terms of scaling, Figure 4 illustrates the number of unicorns per 1 million employees indicating the impact of national startups on the according economy. A unicorn represents a startup of particularly high impact (valuation of at least USD 1 billion), that has successfully passed the stages of commercialization and scaling. With 3.02 unicorns per 1 million employees, the U.S. clearly lead the peer group (EU 27: 0.34; China: 0.20). With 499 unicorns in total, the U.S. is also far ahead of China (165) and the EU 27 (73) in absolute numbers. [12, 15] A major reason for the U.S.'s leading position lies in their startup-friendly ecosystem. It is notable, that startups from tech-driven sectors dominate the share of unicorns across the entire peer group. However, this finding cannot be stated for the German innovation system. While the number of unicorns per 1 million employees in Germany (0.54) is significantly higher than in the remaining EU 27 countries (0.28), they show remarkably fewer tech-driven unicorns. Compared to the remaining European countries (67.5%), only 37.5% of German unicorns allocate in the tech sector. This might indicate that Germany, Europe's leading research nation, needs to catch up when it comes to fostering startups in technology-driven areas.

In conclusion, it appears that the high potential of European, and particularly German research, remains partially unexploited. Further examination of the research and innovation landscape sheds light on potential causes.

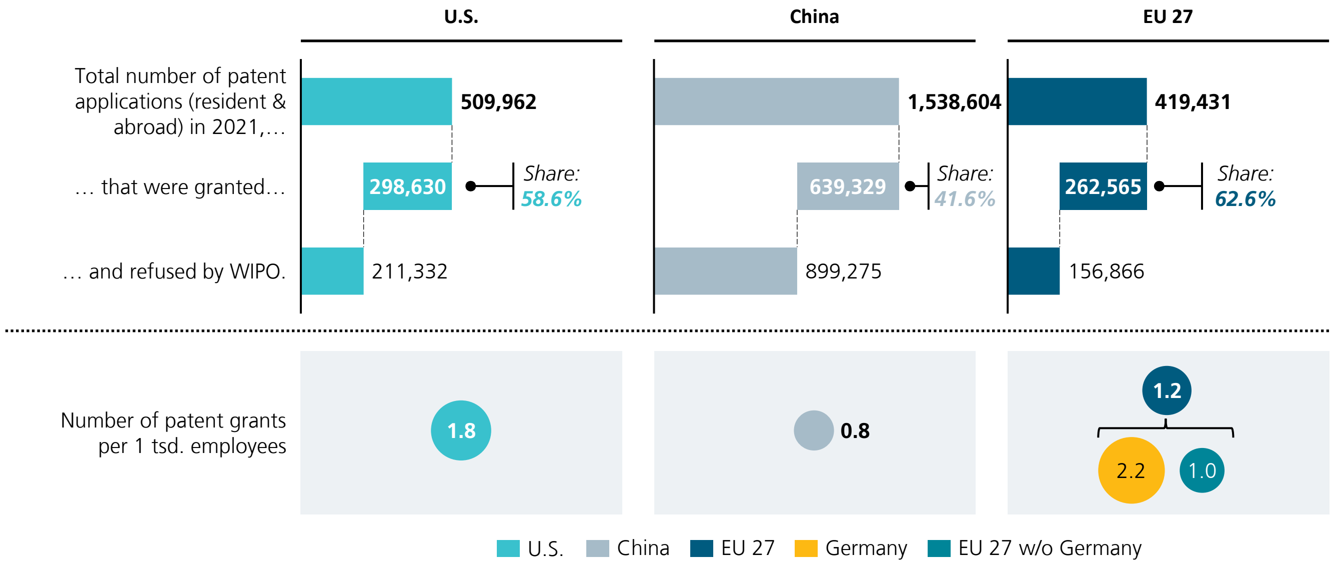

Figure 3: Patents granted relative to the total number of patent applications and per thousand employees in 2021 [11, [12].

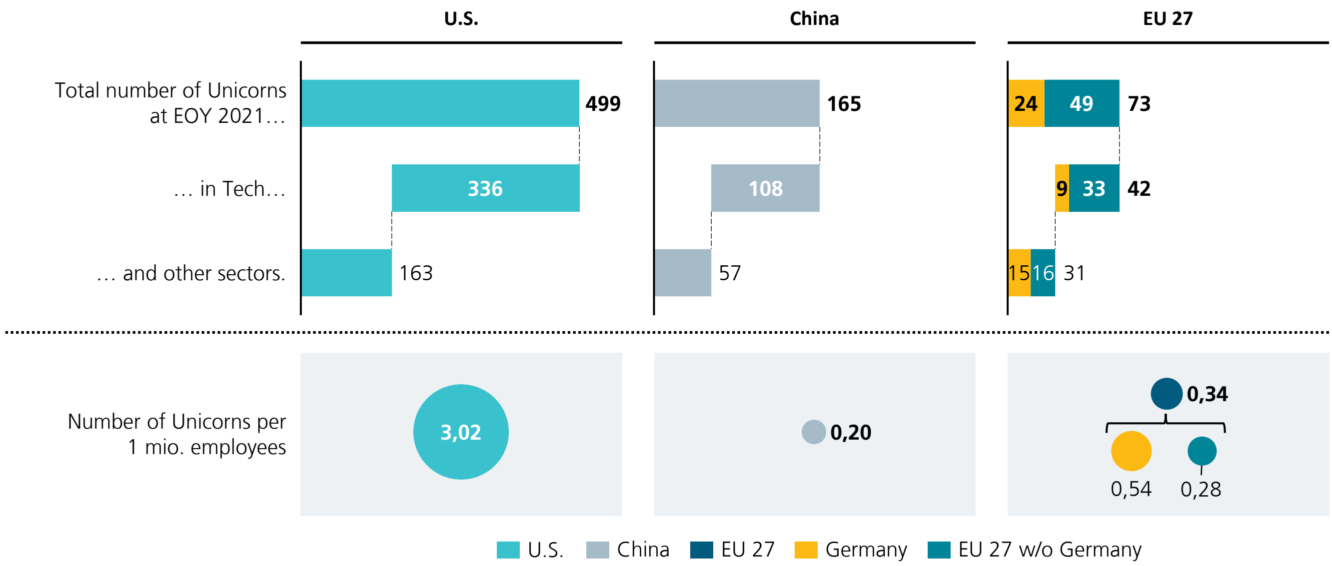

Figure 4: Number of unicorns in tech and other sectors and per million employees in 2021 [12, 15].

Qualitative analysis of the research and innovation landscape

To further deepen the understanding of the peer's innovation systems, the following Section outlines the major traits of their research and innovation landscape. Whilst the focus lies on governmental funding of R&D, commercialization efforts are additionally addressed.

United States

In the U.S., the government accounts for the vast majority of public R&D funding, which is granted through both federal departments (e.g., U.S. Department of Defense) and independent funding agencies (e.g., National Science Foundation) [16]. A breakdown of the total federal R&D spending across agencies is illustrated in Figure 5. While the U.S. government spent a total of USD 158.6 billion in 2020, it is notable that around 80% of these spendings can be attributed to only three federal departments, with the U.S. Department of Defense alone accounting for nearly 40% [17]. Apart from governmental agencies, further sources of funding in the U.S. comprise state agencies, foundations, and corporations [18].

Alongside funding of inventions with mitigated risk, a significant share of their spendings is provided for high-risk inventions with a disruptive character. So-called Advanced Research Projects Agencies (ARPA) are specifically used for this purpose and constitute a key characteristic of the U.S. innovation landscape. These agencies are subordinate to governmental ministries and allocate research funds by means of a person-centered approach via domain-specific experts. In addition to a better assessment of the prospects of success, the flat hierarchies ensure short paths for decision-making, thus accelerating the process of innovation.

In terms of fostering commercialization, the U.S. provide an excellent ecosystem for startups to grow including a substantial number of private investors. In 2021, the U.S. accounted for 49% of globally invested venture capital (VC) (total of USD 683 bil.) with only a 40% share in global VC deals (total of approx. 40,000). While the U.S. share of globally invested VC volume has shown a significant decline throughout the

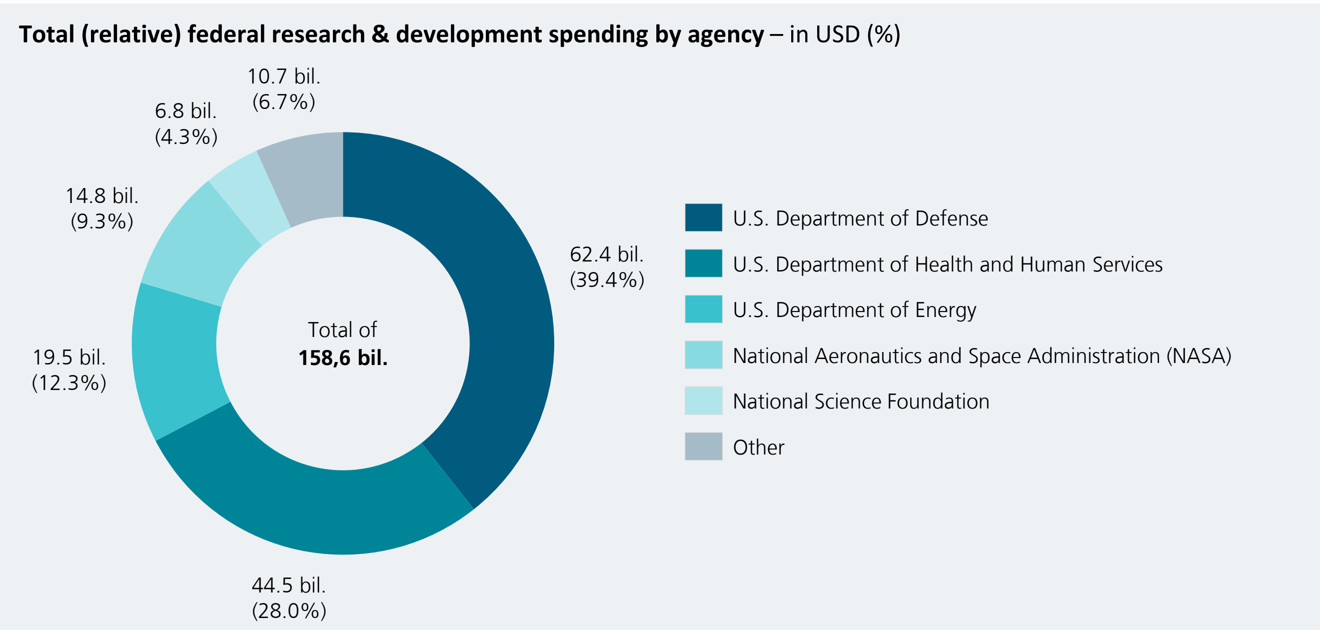

Figure 5: U.S. total and relative federal spendings on R&D by agency in 2020 [17].

previous decade (CAGR 2011-21: -3.2%), they clearly remain in the lead. [19] With a total of 4.7 venture capital and private equity (PE) deals per 1,000,000 employees in 2019, they are far ahead of China (0.3) and the European Union (1.5) [20].

In summary, the U.S. innovation landscape shows diverse opportunities of funding both from public and private sources, with a certain willingness to take risks. This allows for a good transfer from a governmentally driven technology push to a market pull with strong VC and PE. As the potential of disruptive innovations is incorporated to the U.S. innovation landscape, risks are taken at an early stage.

China

The Chinese innovation landscape is characterized by a high level of governmental influence on innovation [21]. The landscape of governmental funding, illustrated in Figure 6, comprises eight funding sources, of which four are considered as key agents [22]. The first key agent is the National Science Foundation of China (NSFC), which focuses on natural sciences and allocates its funds via peer-review processes in addition to committee meetings. The Chinese Academy of Sciences (CAS) is the second major agent, targeting natural sciences, mathematics, and engineering within its six departments. Third is the Ministry of Science and Technology (MOST), focusing on science and technology along four macro strategies. Finally, the Ministry of Education (MOE) is the fourth key agent targeting all types of educational purposes. Other relevant governmental funding agents apart from the key actors are the National Development and Reform Commission, the Ministry of Finance as well as the Chinese Academy of Engineering.

A major trait of the Chinese innovation landscape is its explicit strategic focus that is driven by the government. To operationalize their strategy, China pursues a variety of initiatives. One major initiative is called "Made in China 2025", by which the government aims to sustainably enhance China's manufacturing industry through focusing on ten key sectors . The program comprises the first step in China's long-term strategy to become the world's leading industrial nation by 2049. [23] Other initiatives, such as the "Thousand Talents Plan", aim to foster domestic innovation by encouraging foreign scientists or researchers to relocate to China [24].

When it comes to venture capital and private equity the Chinese market is the second largest globally, with investments growing at a CAGR of +13% between 2010 and 2020 [25]. The substantial growth can be attributed to unique characteristics, as China "is one of only two countries with a population of more than one billion, and the only one of these two with unified language, culture and customs and a centralized government" [25]. Furthermore, China's increasing consumer power, its focus on innovation and continuous regulatory and capital market changes are considered as the major drivers of growth [25]. While China's total VC and PE deal numbers in 2019 were the lowest amongst peers, the average deal volume at USD 21.37 million was higher than the U.S. (USD 18.25 million) and Europe (USD 8.48 million) [20]. However, it is noticeable that domestic investors are over-allocated in China, whilst foreign investors are under-allocated. Reasons for the low allocation of foreign investors lie in language barriers, strict regulation and a significant investment risk due to geopolitical tensions.

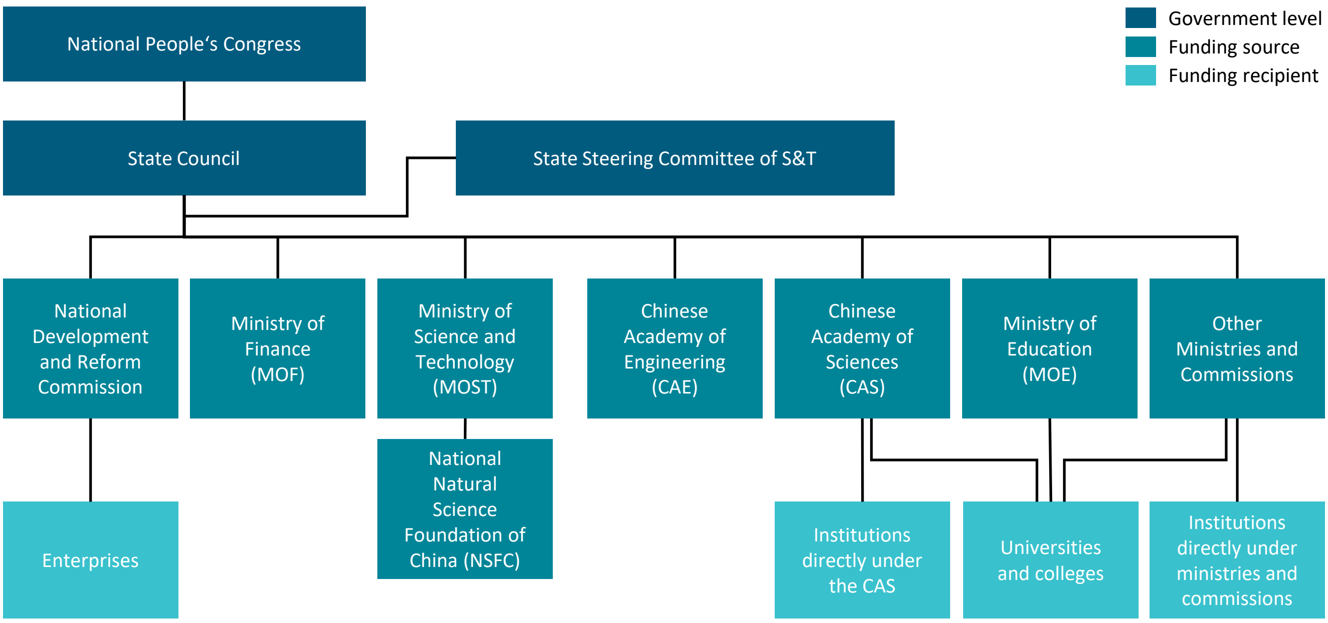

Figure 6: Organizational structure and relations of the Chinese federal funding system for fundamental research [22]

In summary, the Chinese innovation landscape is substantially driven by their government, which both sets a clear strategic focus and fosters the operationalization of their strategy through major initiatives. A domestically oriented VC and PE environment backs the commercialization and scaling of inventions.

European Union (EU 27)
The European innovation landscape is characterized by its high fragmentation. For the 27 member states of the EU, each has its individual regulatory framework and innovation sub-system. In Germany, for example, the Federal Ministry of Education and Research (BMBF) and the German Research Association (DFG) are the major provider of public R&D funding. In addition to the member state's domestic funding, the European Union provides funding programs at a European level (e.g., Horizon Europe or European Innovation Council's (EIC) funding opportunities). Thus, the EU 27 show a high variety of public funding options.

However, in contrast to the U.S., most of this funding is granted via peer-review processes. These help to mitigate risk, but also filter out innovations that are highly disruptive while also protracting the application process. Nevertheless, efforts are increasingly being made to promote the R&D of disruptive innovations in Europe. On a European level, for example, the EIC's Pathfinder program supports the R&D funding of high-risk/high-reward technologies with a total volume of EUR 343 million in 2023 [26]. On a regional level an example from Germany is the federal agency for disruptive innovation (SPRIN-D) that was founded in 2019. The agency, which is conceptiualized based on the U.S. ARPA's, provides a total budget of EUR 1 billion over the course of 10 years. [27] It is notable, that the available budgets for disruptive innovations in the European Union are rather small, especially when compared to the U.S.. This underpins the perception of high risk-aversion in European public funding, which is also reflected in private funding [28].

With a volume of USD 8.48 million per VC or PE deal, average deal sizes are rather low, especially when compared to the U.S. (average of USD 18.25 million) and China (average of USD 21.37 million) [20]. The lower deal volume suggests a lack of sufficiently large financing vehicles, or a considerable risk aversion in European private funding, potentially even both. In addition, European startups face a variety of regulatory constraints from the individual member states and the EU acquis. Around 50% of European startups see overarching challenges in the time required to comply with regulations as well as the tailoring of the regulatory regime towards larger companies [29]. While regulation can decelerate or even impede innovation activities on the one hand, it certainly holds the potential to foster innovation on the other hand. The beneficial and detrimental effects of regulation on innovation capacity require an assessment on a case-by-case basis. [30] A positive example for encouraging innovation is the EU Chips Act, which aims to strengthen Europe's competitiveness and resilience in the semiconductor industry with more than EUR 43 billion in public and private investments [31].

In summary, the European innovation landscape appears to focus on certainty, which is reflected in both public funding during the discovery stage and private funding for commercialization and scaling. A high fragmentation presents additional challenges to all actors involved in the overarching innovation system.

In conclusion, while private investors and corporates provide a fertile ground for startups in the U.S. innovation landscape, China's innovation system is characterized by substantial governmental influence. In contrast, the European innovation landscape is characterized by a high degree of fragmentation and thus a broad variety of funding options.

Recommendations for the European Union

Based on the comparison and the analysis of innovation systems for the U.S., China and EU 27, the major challenges for Europe can be synthesized. Following an elaboration of these challenges, four recommendations with the goal of improving the European innovation system are proposed.

The comparison of the examined peer group members suggests five major challenges for the European innovation system:

Challenge 1: Higher complexity
For the 27 member states of the EU, each has its individual regulatory framework and innovation sub-system. With additional public funding programs on a European level, this leads to a high complexity of funding and coordination throughout the overall innovation system. Language barriers only add to this complexity.

Challenge 2: Lower growth in R&D expenditure
Compared to the U.S. and China, European funding of fundamental research is increasingly falling behind in relative and total volume. Already in 2013, China overtook the EU 27 in terms of gross domestic expenditure on R&D relative to the GDP and has been ahead of Europe ever since. The gap between Europe and the U.S. remains substantial. Note that all members of the peer group show a positive CAGR between 2000 and 2020.

Challenge 3: Less private funding
Compared to the U.S., as the pioneer in commercialization, Europe clearly lacks behind in private funding. This is reflected by a significantly lower number of VC and PE deals per million employees as well as a substantially lower average deal volume seen in 2019.

Challenge 4: Higher risk-aversion
European funding is characterized by a higher amount of risk-aversion. This holds true both for public and private funding. On the one hand, Europe lacks funding sources for the R&D of disruptive innovations with a high-risk high-reward character. On the other hand, a lower average deal volume in VC and PE suggests the reduced risk tolerance of private investors.

Challenge 5: Risk of inhibitory regulation
Rigid and diverse regulation threatens to slow down or even impede innovation activities. Both the European and local regulatory framework affect the entire value chain, from research to commercialization. Insufficient pace in eliminating or decreasing regulatory barriers to innovation poses a substantial risk to the EU and its member states.

To tackle the challenges and maintain its competitiveness, Europe should establish a clear strategic positioning and subsequentially a defined roadmap for operationalization. Within the scope of this work, the following four recommendations are proposed:

Expand public funding for fundamental research at European level

To keep up with its peers, it appears reasonable for Europe to increase their spendings on R&D. Against the backdrop of complexity due to fragmentation, it is advisable to expand public funding at the European level, especially in terms of volume and relevancy. Ultimately, this results in a larger and more consolidated pool of resources and expertise for researchers to access. Furthermore, it increases transnational collaboration in terms of research, which could impact innovation capacity through multinational and heterogeneous teams.

Increase the share and priority of risk-based funding

Exploring disruptive technologies certainly comes with a high level of risk for all actors involved. However, the successful adoption of such technologies holds an enormous market potential. It is therefore advisable to strive for a healthy balance between rather certain and higher-risk research. As Europe currently tends to the more certain end, it seems reasonable to increase risk capital for both private and public funding. Germany's SPRIN-D program is heading in the right direction, although it is debatable whether it is too undercapitalized. Thus, following the U.S. ARPA agencies as well as their VC and PE environment is highly suggested.

Establish a regulatory environment that fosters innovation

As shown previously, regulation holds the potential to either foster or inhibit innovation. To increase Europe's competitiveness, it is therefore advisable to establish a regulatory environment that stimulates innovation along the entire value chain. This also requires for the regulatory framework to consider all actors involved in the innovation system. Examples include comprehensive and EU-wide governance for private investors, one-click incorporation of startups or the employees' right to contribute their own inventions in a firm without waiving their intellectual property rights.

Create stronger incentives for domestic founding and settlement

For Europe to benefit from the market impact of successful startups, it is vital to retain them locally. Thus, strong incentives for domestic founding and settlement appear to be crucial. At early stages these may include the stronger support, mentoring and guidance for startups, as well as the availability and accessibility of real laboratories (e.g., Fraunhofer Research Institution for Battery Cell Production FFB). In subsequent phases, more late-stage funding and adjacent resources are required to avoid corporate migration abroad. A positive example of fostering and retaining innovation in Europe is the EU Chips Act.

We certainly expect that the strategic integration of the above recommendations will foster Europe's competitiveness in terms of innovation. To realize success, the next step lies in developing adequate incentives to operationalize these recommendations.

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