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Focus on Critical Key Technologies: The Race for Leadership in Industry and Technology Policy*

KEY MESSAGES

- **Technological sovereignty can be defined as the ability of a country to guarantee access at all times to the key technologies that are necessary to meet social priorities and needs**
- **Despite having different competences, the countries analyzed focus largely on the same fields of technology that are expected to generate value in the future**
- **Measures to promote technological sovereignty are heterogenous across countries and range from the promotion of R&D activities to subsidies for setting up industrial plants**
- **Systematic predictions of technological trends would enable policymakers to deal with new technologies at an early stage and adapt policy measures and institutions**

Many nations are investing more in critical technologies than ever before. Numerous governments have launched programs in the past two years aimed at promoting technological sovereignty, focusing on key enabling technologies. However, these programs are often only partly motivated by innovation policy. Fundamental objectives of national security and competitiveness vis-à-vis other countries also play key roles, against the backdrop of a shifting perspective on globalization. Geopolitical fragmentation and the recent experience of broken supply chains during the pandemic have placed technological sovereignty on the agenda. The programs are generally backed by significant funding. In this paper, the Council for Technological Sovereignty of the German Ministry for Education and Research (BMBF) provides a comparative overview of critical technologies and the institutional governance of technological sovereignty in selected countries.

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KEY OBJECTIVES OF TECHNOLOGICAL SOVEREIGNTY

The pursuit of "technological sovereignty" has become an important topic in politics and business over the past decade. Based on the Council for Technological Sovereignty's definition, this can be understood as the ability of a country to guarantee access at all times to the key technologies that are necessary to meet social priorities and needs.

The goals of technological sovereignty have changed over time. Originally, they focused mainly on military research. As the digital transformation progressed and the importance of digital infrastructure, platform business models, and cloud computing increased, digital sovereignty took center stage. Debates centered, for example, on network components from Chinese manufacturers in domestic mobile networks, regulation of large platform operators, and the importance of a European cloud infrastructure. Later, the fight against climate change and the need for a faster energy transition came to the fore: in this context, sovereignty in environmental and energy technologies became the main topic of discussion. In the meantime, the focus has also shifted to technologies that are expected to make a significant contribution to global value creation in the future.

One current goal is to shield ourselves against geopolitical risks. These have gained prominence due to the increasing polarization and fragmentation of global markets. Concerns about developments in China, an autocratic country that is rapidly developing its technological prowess, the impact of the Covid-19 pandemic on healthcare systems and supply chains, the weakening of globalization, and the urgent need for measures to combat climate change all play a central role. Trust in transnational solutions has

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Table 1

Overview of Industrial and Research Policies in Selected Countries and the EU

	Germany	European Union	USA	China	Japan	South Korea
Number of key technology areas	12 "key technologies"	10 "critical technology areas" with 4–5 technologies each (42 technologies in total)	19 "critical and emerging technologies" with 2–15 "critical and emerging technology subfields" each (103 subfields in total)	7 "cutting-edge areas of science and technology" with 3–5 specifications each (28 in total)	20 "technologies as critical fields"	12 "strategic technologies"
Strategies	"Shaping the future with technological confidence," BMBF impulse paper, April 2021	Commission recommendation on security-relevant technology areas, October 2023[1]	"United States government national standards strategy for critical and emerging technology," May 2023	14th Five-Year Plan, March 2021	"Economic security strategy," February 2022	"National strategic technology nurture plan," October 2022
Institutions	Various institutions at the federal level: BMBF, BMWK, BMDV, Federal Chancellery	Steering board of sovereignty	Office of science and technology policy in the White House Special envoy for critical and emerging technology	Ministry of science and technology of the People's Rep. of China	Council of experts on economic security legislation Japan science and technology agency	Ministry of science and ICT National strategic technology special committee
Central goal	Preserving values, securing prosperity and jobs	Strengthening the economic basis and competitiveness, protection against risks (disruptive technologies, dual use, risk of misuse)	Economic leadership in future technology, national security and self-sufficiency in selected areas of technology	"Self-reliance"	Economic security	Technological supremacy
Investments (2019 estimate)[2]	$ 19 billion PPP (0.41 % GDP)	n. a.	$ 84 billion PPP (0.39% GDP)	$ 406 billion PPP (1.73 % GDP)	$ 27 billion PPP (0.5 % GDP)	$ 15 billion PPP (0.67 % GDP)
Selected support measures[3]	$ 5.4 billion by 2025 for the AI strategy $ 3.3 billion in quantum computers by 2026	$ 294 billion for the "Green industrial deal" $ 141.5 billion for "NextGenerationEU" $ 762 million for 5G infrastructure (Horizon 2020) $ 980 million for smart networks and services	$ 369 billion IRA $ 230 billion for semiconductor production $ 140 billion for electric vehicles and batteries $ 20 billion for biomanufacturing	$ 1,400 billion for new infrastructure: 5G, AI, IoT, etc. $ 150 billion for a next-generation AI development plan	Investments are to come primarily from the private sector. In addition, $ 1.05 trillion is to come from public-private partnerships over the next 10 years[4]	$ 430 billion for semiconductors over 23 years $ 10 billion for biotechnologies by 2026 $ 73 billion for mobility/vehicles by 2026 $ 1.3 billion for robotics by 2026[5]

Note: The complexity of the funding landscape of industrial and research policy channels makes it difficult to aggregate all the respective measures and investments. The table therefore contains a representative selection. Due to the limited data available, scientific work from 2019 was used in some cases, even if lists of key technology fields were not compiled until later. [1] Mentions of strategic autonomy since 2013: https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/733589/EPRS_BRI(2022)733589_EN.pdf; [2] di Pippo et al. (2022); [3] Exchange rates calculated December 14, 2023; [4] https://www.meti.go.jp/english/policy/economy/industrial_council/pdf/0727_001.pdf; [5] https://www.meti.go.jp/english/policy/economy/industrial_council/pdf/0727_001.pdf. PPP = purchasing power parity.

Source: Authors' compilation.

fallen significantly, with countries increasingly relying on national approaches or cooperation with "friendly nations." The spectrum ranges from "as little as necessary" to "as much as possible": China, for example, speaks of "self-reliance," the US of "economic and national security," and the EU of "strategic autonomy."

THE MOST IMPORTANT CRITICAL TECHNOLOGIES

What technologies do the countries selected for this analysis focus on in the context of technological sovereignty? To answer this question, we assessed strategy papers – both government publications and secondary literature – addressing technological sovereignty and the national promotion of critical technologies in Germany and the European Union, the US, China, Japan, and South Korea. In addition, we conducted interviews with experts for the funding programs of the individual countries studied, aiming to shed light on the strategy and motivation behind the countries' programs.

Overall, the assumption that technological sovereignty is highly relevant internationally was validated. The terminology used in this context, however, differs from country to country: while some countries speak of "key technologies" or "key enabling technologies," others define "prioritized" or "critical" or "frontier" technologies. The degree of national autonomy that is pursued for these technology areas also varies greatly.

The characteristics and priorities of the lists differ in their basic structures, where some are available as a one-dimensional list and some as a list with super- and subcategories. In some cases, identical technology areas are categorized into different priority levels, and some countries even include technology-intensive fields of application or industry-specific solutions in their lists. All these aspects make a direct comparison between countries difficult.

Nevertheless, there is significant overlap between the technology lists of countries in our sample. The greatest consensus can be found in the areas of artificial intelligence, quantum technologies, biotechnology, microelectronics/semiconductors, information and communication technologies, and production technologies/Industry 4.0. But even beyond these, the lists of technologies considered relevant are very similar – although there are certain divergences in some areas. Germany, for example, gives significantly higher importance to research into green hydrogen than most other countries. The US and Japan have a special focus on "hypersonic" technologies, which are particularly relevant as the basis for launch vehicles in dual-use applications. Environmental and recycling technologies receive special attention only in the EU and the US, while they are not listed in Asia. Japan, China, and South Korea also mention deep-sea and deep-earth exploration as relevant research areas, whereas this is not the case in the EU or the US.

The process of selecting technologies differs significantly between countries. Although the details of the process cannot be fully grasped everywhere, it is clear that the US and China in particular have institutionalized this process. The US, for example, established the Fast Track Action Subcommittee on Critical and Emerging Technologies in 2020 specifically for the purpose of identifying such technologies.

In Germany, on the other hand, the process is spread across several stakeholders within the federal government. There is no cross-departmental list of critical technologies, even if there is a great deal of agreement between the focal points of the Federal Ministry of Education and Research (BMBF) and the Federal Ministry for Economic Affairs and Climate Action (BMWK). The situation is similar in the EU, where – in particular due to the decentralized structure and diverse perspectives of the member states – new lists with varying degrees of detail are constantly being published (European Commission 2023; Allenbach-Ammann 2023).

In general, each compilation of the relevant technologies follows the overarching political and economic objectives of the respective country, with competition and industrial policy objectives, as well as the strengthening of the respective lead industries, reflected in the programs' details.

FUNDING FOR TECHNOLOGICAL SOVEREIGNTY

The countries analyzed are following different approaches, including industry- and technology-funding programs, regulatory restrictions on market access for certain companies, and restrictions on exports of critical materials. A look at the semiconductor industry illustrates this development: the US has committed to investing USD 280 billion in chip production and research over the next ten years, China is providing subsidies totaling USD 145 billion, and the EU has passed a law allocating EUR 43 billion to promote chip production in Europe. In Germany – subject to budgetary realities – billions in subsidies are planned for the construction of chip production plants, for example by Intel or TSMC. At the same time, there is a trend in some countries to restrict access to key components that are essential for chip production. China, for instance, has been restricting the export of critical minerals such as gallium and germanium since August 2023, while the US has imposed export restrictions on EUV lithography equipment – critical for chip production – to China.

The diversity of funding approaches makes it difficult to quantify the funding volumes across countries and technologies or technology-intensive applications. Various institutions are nonetheless making an attempt at quantification.[1] The Center for Strategic and International Studies, for example, estimates the expenditure on industrial policy strategies for China and seven other economies (Brazil, France, Germany, Japan, South Korea, Taiwan, and the US) (DiPippo et al. 2022). The study suggests that industrial policy is an important part of these countries' policymaking toolbox.

Similarly, the OECD has developed cross-country methods for quantifying industrial policy for a selection of its member countries (Criscuolo et al. 2022). According to these methods, an average of around 1.4 percent of GDP was spent on support measures such as project funding, grants, and tax breaks, and a further 1.8 percent of GDP on loans. The approach is largely technology specific. Funding for explicitly sustainable projects has increased significantly in recent years (Criscuolo et al. 2023).

Another approach uses natural language processing (Juhász et al. 2022) to classify industrial policy at a high-resolution level (country-industry-year) based on publicly available descriptions of policy measures (Global Trade Alert n.d.). The core idea is that textual descriptions of programs often convey information about the objectives of policy actors and allow researchers to determine whether a policy pursues industrial policy objectives or alternative objectives (Juhász et al. 2022). Industrial policy is often granular and technocratic, and only individual companies benefit from the funds. Furthermore, these support measures are primarily applied in wealthier countries and are usually targeted at a specific industrial sector that is considered central to competitiveness and prosperity.

The following table provides an overview of the number of specifically listed key technology areas, associated strategies, participating institutions, stated goals, corresponding investments and selected funding measures for six countries or communities of states analyzed.

[1] Source of the summary: Juhász et al. (2023).

OBSERVATIONS AND DISCUSSION

The brief overview presented here supports three observations:

Same Thrust – Different Competences

The countries analyzed focus largely on the same fields of technology that are expected to generate value in the future. Even if there are certain differences between the countries when it comes to setting priorities within the technology fields, it is possible to ascertain the extent to which the selection process incorporates individual countries' strengths into specific technology fields and possible specialization advantages. After all, technological sovereignty does not necessarily mean each national entity (further) developing all technologies by itself, but rather that access to key technologies should be guaranteed at all times.

What does technological sovereignty mean in the technology-intensive area of robotics, for example? In robotics, Germany is well-positioned in engineering, presumably securing its technological sovereignty directly in this field. AI, on the other hand, which is becoming increasingly important for smart robotics, is being furthered primarily in other countries. This raises the question of the extent to which access to the relevant AI developments is guaranteed at all times in order to ensure technological sovereignty in this aspect as well.

Promotion of Production Capacities vs. Promotion of R&D

In the measures to foster technological sovereignty, the distinction between promoting R&D activities and furthering the development of production capacities is becoming increasingly blurred.

Public funding of R&D activities goes largely unchallenged due to significant (locally limited) knowledge spillovers. A certain mission-oriented approach aimed at solving urgent social problems, such as decarbonization, has prevailed over the isolated promotion of individual technologies in the R&D funding landscape.

In contrast, public support for the development of production capacities raises the question of the risk of an inefficient international division of labor. Do such measures still fully utilize a country's comparative advantages and the benefits of international trade? To what extent is the promotion of domestic production a sensible response to new geopolitical tensions and to concerns about dependence on foreign countries for certain (intermediate) products? Costly reshoring can probably be only part of the solution to ensure the resilience of value chains for high-tech goods. Multi-sourcing, which can also include friend-, near-, or reshoring, is more likely to be helpful. What might other approaches look like for shielding a country against unforeseeable geopolitical tensions? Can suitable measures be applied and conditions devised to create mutual dependencies through the production and export of intermediate products and inputs that yield a strategic advantage?

Public support for production should also take the lifecycle of an industry into account. In the case of a nascent industry, public funding could achieve learning effects in production so that new products become competitive more quickly compared to (inferior) old products. However, the nascent industry argument justifies only the temporary promotion of such industries, and that promotion should be reduced as the industry matures. This often poses a political-economic problem: the difficulty of withdrawing support once it has been granted.

Promoting the establishment of production capacities at the expense of foreign countries is often seen as a zero-sum game. It is assumed that there is a "pie" of a given size that needs to be distributed between countries. However, this view overlooks the growth-generating benefits of international trade and cooperation. It often also triggers a spiral of intervention and subsidization between countries that is not only harmful for all countries in the long term, but also for each individual country, since each country's scarce resources – including skilled labor – are not put to their most productive use.

Possibilities for Early Detection of Technological Trends

Some countries, such as the US and China, have institutionalized and professionalized the process of monitoring emerging technologies. Even if monitoring is no guarantee of good policy decisions, it does allow policymakers to deal with new technologies at an early stage and, if necessary, adapt political conditions and institutions.

THE GOAL OF TECHNOLOGICAL SOVEREIGNTY

This paper also illustrates that very different goals, and therefore different policy measures, may lie behind the concept of technological sovereignty in different countries. In a world of rapidly changing geopolitical conditions and new technological developments and trends, perhaps the most compelling goal of technological sovereignty is to avoid one-sided dependence in accessing key technologies and inputs that are necessary to meet societal priorities and needs. Measures to promote technological sovereignty should therefore be gauged against the achievement of this goal.

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