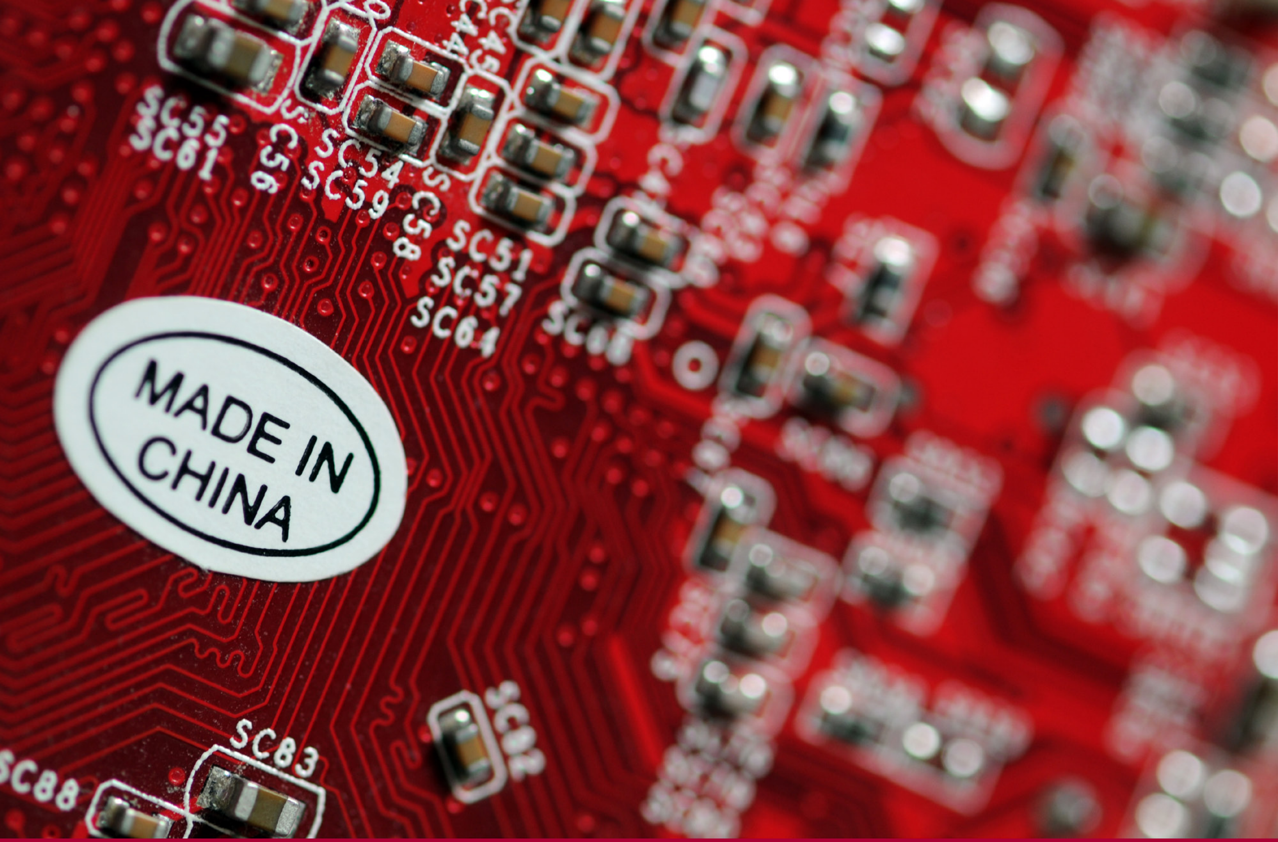

Innovation Capacity in the People's Republic of China

On the state of the innovation assessment literature and strategic ambitions in science and technology governance

Frida Lampinen & Anders Schröder

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Sammanfattning

I takt med att spänningarna mellan Kina och västvärlden har ökat så har innovation blivit centralt för att få ett övertag i stormaktsrivaliteten. Ett teknologiskt försprång kan ge både ekonomiska och militära fördelar. Fram till nyligen ansågs Kina vara oförmöget till innovation, men detta perspektiv har förändrats dramatiskt och nu tyder många studier på att Kina kan vara på väg att överträffa västvärlden inom teknologi och vetenskap.

Den här rapporten ger ytterligare bakgrund till diskussionen om rollen av innovation i stormaktspolitik. Vi undersöker vad det innebär att ligga före eller efter i innovationsförmåga, hur vi kan mäta det, och hur Kinas innovationskraft kan tänkas utvecklas framöver. Rapporten konstaterar att kvantitativa studier som jämför kinesisk och västerländsk innovationsförmåga tenderar att främst mäta uppfinningsförmågan. Detta innebär att viktiga aspekter av teknologikonkurrensen inte fångas upp, och att kompletterande kvalitativa studier behövs för att få en fullständig bild.

Xi Jinping har stora strategiska ambitioner för att utveckla och tillämpa Kinas innovationskraft, men den nationella politiken på området spelar bara delvis på det kinesiska systemets styrkor. Detta indikerar att de egenskaper som har möjliggjort Kinas framsteg inom innovation - inklusive dess stora befolkning, marknad och driftiga företag – framöver kan visa sig mindre betydelsefulla i en förändrad ekonomisk, demografisk och regleringsmässig miljö.

Nyckelord: Kina, innovation, försvarsforskning

Summary

As tensions between China and the West have increased, innovation has become central to gaining an edge in their great-power rivalry; a technological advantage can provide both economic and military benefits. Until recently, China was considered unable to innovate, but this perspective has shifted dramatically and now many reports suggest that China may be surpassing the West.

This report provides further context to this discussion, exploring what it means to be ahead or behind in innovation, how we can measure it, and the implications for China's innovativeness going forward. The report finds that quantitative reports comparing Chinese and Western innovation capacity tend to primarily measure *invention* capacity. This means that important parts of the innovation race are not captured by quantitative studies, and complementary qualitative studies are needed in order to gain a full picture.

While Xi Jinping has grand strategic ambitions for China's innovation power, national policies only partially play on the Chinese system's strengths. This indicates that the characteristics that have allowed China to advance in innovation—including its large population, market, and prominent enterprises—may be less consequential in a changed economic, demographic, and regulatory environment.

Keywords: China, innovation, defence research

Preface

This report is produced within the Swedish Defence Research Agency's programme on weak signals. The programme provides analyses to the Swedish Ministry of Defence on the topic of new and emerging technologies and their implications for defence and security. Within the programme, work is done both to identify and assess potential new technologies at the research frontier, as well as to analyse technology and innovation more broadly in order to provide context for how emerging technologies may affect defence and security issues in the future. This report falls into the latter category.

Eva Dalberg

Programme Manager for the Weak Signals Programme.

Stockholm, May 2025.

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Thanks to Tim Rühlig for reviewing this report, and for sharing your expertise with us. We are also grateful for the language editing assistance from Richard Langlais and for layout support from Lena Engelmark.

Executive Summary

As tensions between China and the West have increased, innovation has become an essential tool in order to gain an edge in their great-power rivalry. A technological advantage can provide both economic and military benefits and innovative capacity is the way to achieve that advantage. Up until relatively recently, the West considered that China was unable to innovate. This perspective has shifted dramatically, however, and now many reports instead suggest that China may possibly be surpassing the West in innovative capacity.

This report provides further context to this discussion, exploring what it means to be ahead or behind in innovation, how we can measure it, and the implications for China's innovativeness going forward.

The report is separated into two parts. The first part looks at how other major quantitative reports have compared Chinese and Western innovation capacity. Those reports find China quickly catching up to the West. However, they tend to focus on only part of the diffusion process, measuring primarily invention capacity (such as the number of cited articles or the number of patents). Some reports also measure diffusion capacity, meaning how technologies are adopted throughout the economy.

The reports only rarely, however, measure incubation or implementation, meaning how an invention gains status and influence, and eventually becomes adopted and applied throughout an organisation. This means that important parts of the innovation race are not captured by the major quantitative studies on the subject, and complementary qualitative studies are needed to gain a full picture on the race for innovative capacity.

Second, the report examines the strategic incentives for Chinese innovation to understand its efforts going forward. Domestic discourses attribute the downfall of the Chinese empire in the 19th century partly to its technological inferiority. To reclaim the nation's global status, the Chinese Communist Party has dedicated much time and effort to upgrading its technological capacity. The Party's science and technology (S&T) policymaking follows three strategic incentives: economic development, military power, and global influence. Xi Jinping's policies largely build upon previous initiatives, but are distinct in their paramount security focus and innovation-centric messaging.

Official rhetoric portrays the strategic competition as a confrontation of political systems and seizes every opportunity to use innovation as proof of the superiority of Chinese socialism. The driving force for transforming inventions into generating economic, military, and international political power effects is domestic market interests. However, a comparison between the focus areas of Xi's policies and the Chinese innovation system's strengths indicates that the market's ability to absorb new inventions may be reduced in a changed economic, demographic, geopolitical, and domestic regulatory environment.

Abbreviations

4IR	Fourth Industrial Revolution
AI	Artificial intelligence
AIDP	Artificial Intelligence Development Plan
ASPI	Australian Strategic Policy Institute
CCP	Chinese Communist Party
CNKI	China National Knowledge Infrastructure
GDP	Gross domestic product
IDAR	Introduction—Digestion—Absorption—Re-innovation
IDDS	Innovation-driven Development Strategy
IP	Intellectual property
ITIF	Information Technology & Innovation Foundation
MCF	Military-civil fusion
MIC25	Made In China 2025
MLP	National Medium- and Long-term Plan for S&T Development
NIS	National innovation system
OECD	Organisation for Economic Cooperation and Development
PLA	People's Liberation Army
PRC	People's Republic of China
R&D	Research and experimental development
S&T	Science and technology
ARWU, Shanghai Ranking	Academic Ranking of World Universities
SOE	State-owned enterprise

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1 Introduction

In public debate, "innovation" has become a buzzword often applied to all sorts of things that are seen as good or new. In the academic literature, innovation studies link innovation capacity to economic growth, improved standards of living, and national power. Similar perceptions of the benefits of innovation exist on a popular level, too. According to a 2015 Eurobarometer survey, a majority of European Union (EU) citizens believe science and technological innovation will have a positive impact on climate change, public health, and education within the next 15 years.[1] Similarly, more than 80 percent of Americans believe that science provides more opportunities for the next generation.[2]

At the same time, the relationship between innovation and national power is playing out in the growing technological rivalry between the United States (US) and China. Ten to fifteen years ago, Western observers widely held that the People's Republic of China (PRC) could not innovate. China's authoritarian political landscape, a lack of academic freedom, reward structures based on quantitative performance, the lack of IP rights protection, and an unpredictable market are all reasons cited for why China was fated to remain a science and technology (S&T) copycat.[3] However, investments in science and technology have increased explosively in the PRC since the 1990s, and a shift in Western attitudes has followed—the title of a 2024 article in *The Economist*, "China has become a scientific superpower," is telling in this regard.[4]

Indeed, under Xi Jinping's leadership, innovation-centrism has become a distinctive characteristic of top-level policymaking, where multiple authoritative documents present innovation as the solution to a broad range of social, environmental, financial, and security challenges. Most notable in scale, scope, and ambition is the Innovation-Driven Development Strategy (IDDS) issued in 2016. In calling for China to become a "world S&T innovation superpower" by 2050 and decreeing, "national prosperity follows from strength in innovation, and national misfortune follows from weakness in innovation," the IDDS leaves no room for ambiguity as to the regime's convictions.[5] The IDDS also declares that China should reverse its traditional technology dependencies (so as to make other nations

[1] European Commission, Directorate-General for Communication. *Special Eurobarometer 419: Public perceptions of science, research and innovation (v1.00)* (2015).

[2] Brian G. Southwell & Benjamin Schneider. *Science and Technology: Public Perceptions, Awareness, and Information Sources* (National Science Board, February 14, 2024).

[3] C.f. Regina M. Abrami, William C. Kirby & F. Warren McFarlan. Why China Can't Innovate. *Harvard Business Review* (March 2014); Will China Achieve Science Supremacy? *The New York Times: Room for Debate* (18/1 2010).

[4] C.f. Zak Dychtwald. China's New Innovation Advantage. *Harvard Business Review* (May-June 2021); China has become a scientific superpower. *The Economist* (12/6 2024).

[5] Central Committee of the CCP & PRC State Council. *Outline of the National Innovation-Driven Development Strategy* (CSET Translation, 2019).

dependent on Chinese inventions in S&T) by 2030. In practice, China is the second-biggest spender on research and development in the world—after the United States—accounting for about 26 percent of the global share in 2023.[6] To put things into perspective, China's research spending in 2024 (almost USD 495 billion) was greater than the total gross expenditure of the governments of 157 countries around the world.[7]

It is therefore unsurprising that various perspectives on innovation feature heavily in the contemporary debate on US-China strategic competition. But what do observers mean when they state that the US, or China, is more innovative than the other? And what do potential discrepancies in definition mean for the technological rivalries unfolding on the international stage?

1.1 Purpose and research questions

The goal of this report is twofold. First, the report aims to bring clarity to what the existing literature is talking about—and what it is not talking about—in assessments of China's innovation capacity. A central contribution in this regard is a breakdown of the term *innovation* into a more precise analytical model, which is then used to analyse three well-known quantitative studies that compare Chinese and US/Western innovation. By differentiating between different aspects of innovation, the report highlights which aspects of innovation can easily be measured quantitatively, and which aspects require other tools and further studies in order to gain a more complete picture. More specifically then, the research questions for the first part of the report are:

- What do major quantitative studies mean when they talk about China's innovation capacity?
- Are there aspects of Chinese innovation capacity that are less emphasised in these reports? If so, what are they?

These questions have implications not only for future research but also for policymaking, as a proper understanding of the available data is essential for drawing the right conclusions.

Second, the report aims to provide a better understanding of China as an innovation actor. We hope that readers of this report gain a fundamental grasp of why China is pursuing innovation, what characterises Chinese innovation, and some implications of Xi Jinping's S&T policymaking approach for China's ability to reach its goals. The report does this by analysing the strategic motives underpinning China's science and technology policy, in the past and presently. This is followed

[6] Davide Bonaglia, Lorena Rivera León & Sacha Wunsch-Vincent. End of Year Edition – Against All Odds, Global R&D Has Grown Close to USD 3 Trillion in 2023. *WIPO* (2024-12-18).

[7] PRC State Council. China's R&D Spending reports rapid growth in 2024. (2025-01-23); World Population Review. *Government Budget by Country 2024* (2024).

by an examination of the characteristics of the Chinese mode of innovation and how Xi Jinping's S&T policymaking plays upon or overlooks systemic strengths.

The analysis in the second part of the report is guided by three questions:

- Why do Chinese decision-makers value innovation capacity so highly and how does the CCP envision using innovation to fulfil the PRC's strategic goals?
- What systemic features may have enabled the PRC's shift from "copycat" to "emerging S&T powerhouse"?
- And what measures of Chinese S&T policies under Xi Jinping stimulate which phase(s) of the innovation process?

It is not within the scope of this study to describe China's practical progress (in terms of, e.g., research infrastructure, patents, or research quality) or to assess how well these results meet policy targets.[8] Moreover, the analysis in Chapter 5 does not claim to be a comprehensive assessment of the issue at hand. The study does, however, provide a perspective on the efficacy of Beijing's approach to S&T policymaking in general, which we hope will be useful for policymakers, innovation actors, government officials with China-related work portfolios, scholars, and interested members of the public who seek to understand China's innovativeness.

1.2 Methods and sources

This report employs various qualitative textual analysis methods. The analytical work presented in Chapter 3 is similar to content analysis, where the material was codified according to a set of instructions based on the analytical model presented in Chapter 2. Chapter 3 describes the methodology for the analysis in detail, and presents the source material. The analysis in Chapters 4 and 5 draws upon a broad literature review. The source material include academic literature, research reports, monographies, news articles, and websites, among others, in English and Chinese. The analytical work in Chapter 5 employs content analysis, the method for which is presented in the chapter alongside the sources and results.

1.3 Structure of the report

This report is structured into two main parts. Part One, comprising Chapters 2–3, situates the report in a theoretical context and critically reviews the current state

[8] The state of China's innovation efforts has been described elsewhere, and for the purposes of this study it is not relevant to repeat all the statistics. For interested readers, we recommend Cong Cao. *Innovation in China: Domestic Efforts and Global Integration* (IGCC & MERICS, May 2024); Jonathan Adams, Ryan Fry, David Pendlebury, Ross Potter & Gordon Rogers. *Global Research Report: China's research landscape* (Institute for Scientific Information, October 2023).

of innovation research on China. Chapter 2 begins by reviewing the fundamentals of innovation theory, introducing relevant concepts and laying down central definitions. A focal point is the notion of innovation measurements. The chapter also presents the innovation process model, which is the analytical lens assumed by our research approach. Following this, Chapter 3 analyses three central reports that assess China's progress in innovation in science and technology.

Part Two, comprising Chapters 4–5, explores governance in Chinese innovation and technology policy. Chapter 4 places China's innovation ambitions in a historical context. It tracks the interaction between strategic objectives throughout the PRC's S&T policy history and briefly examines some characteristics and strengths of the Chinese mode of innovation, by means of which the country has been able to progress so rapidly in S&T. Chapter 5 turns the attention towards the "how," i.e. central strategy and policy documents adopted under Xi Jinping to advance China's innovation capacity. The chapter concludes with an analysis of the implications of China's approach to achieving its innovation goals, as seen from an innovation process model perspective. Finally, Chapter 6 ends the report with a discussion and suggestions for future research.

2 Innovation theory

2.1 Defining innovation

In order to study China's innovation capacity and what it might mean for the strategic competition between China and the West, it is necessary to clarify how we define innovation. For most of history, innovation was synonymous with invention, novel ideas, and new discoveries. New ideas and practices have not always been welcome in historical societies, where the societal elite often had low tolerance for social and economic change.[9] Only in the mid-18th century did innovation begin to gain the positive connotations of progress, modernisation, and creativity in Western discourses, though it still referred exclusively to new knowledge. A notable aspect of contemporary innovation definitions, however, as pioneered by Joseph Schumpeter in the early 20th century, is that innovation is not restricted only to new inventions, but also includes new uses and combinations of pre-existing knowledge elements.[10]

Schumpeter's work on innovation and economic growth solidly established innovation studies as an emerging field. After the end of World War II, innovation started attracting massive attention from all sorts of academic disciplines, including economic development, business management and organisation studies, psychology, sociology, political science and international relations, anthropology, and science and technology studies, among others. This multidisciplinary use of innovation theory also means that the term is used in several, often inconsistent, ways.[11] At times, innovation refers to invention and technological or organisational change; at other times to the spread and adoption of knowledge; and yet other times to multiple aspects all at once.

Therefore, it is unsurprising that many, sometimes contradictory, definitions for the term exist.[12] For example, Baregheh, Rowley, and Sambrook compare 60 different definitions of innovation within a number of fields and distil them down to the following:

> "Innovation is the multi-stage process whereby organizations transform ideas into new/ improved products, service or processes, in order to advance, compete and differentiate themselves successfully in their marketplace."[13]

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9 Mark Zachary Taylor. *The Politics of Innovation: Why Some Countries are Better Than Others at Science and Technology* (Oxford University Press, 2016): pp 301–302.

10 Karol Śledzik. Schumpeter's view on innovation and entrepreneurship. *SSRN Electronic Journal* (2013).

11 Anahita Baregheh, Jennifer Rowley, & Sally Sambrook. Towards a multidisciplinary definition of innovation. *Management Decision*. 47:8 (2009): pp. 1323–39.

12 A more comprehensive overview of different definitions can be found in Marcus Tynnhammar. "*Innovation— Trends from research"* [Innovation— en grundläggande kunskapsöversikt över civila trender inom forskning] (FOI, 2023).

13 Baregheh et al. Towards a multidisciplinary definition of innovation.

The Organisation for Economic Cooperation and Development (OECD), a central actor in the global innovation landscape largely responsible for both standardising innovation measures and setting the agenda for building innovative capacity, provides yet another definition. They describe innovation as:

> "A new or improved product or process (or combination thereof) that differs significantly from the unit's previous products or processes and that has been made available to potential users (product) or brought into use by the unit (process)."[14]

The definitions above share a recognition that innovation does not have to include changes in technology. Innovation can also mean using existing resources, for example personnel in an organisation, in new and hopefully more efficient ways. The above definitions differ however, in their view of innovation: Is it a process, or the outcome of a process? In the first case, innovation as a process refers to the work done to create a new/better product, service, or process. In the latter case, innovation as the outcome of the process refers to the actual improved product, service, or process that the work led to. Since the goal of this report is to improve the understanding of the competition for power, we are ultimately interested in the outcomes, meaning the new products, services, or processes, since they are what will affect the balance of power between the actors. Therefore, it makes sense for this study to use the OECD definition of innovation. However, when studying the innovation capacity of the actors, the processes that lead to the outcomes will be just as important for us to understand. Thus, this paper distinguishes between the two. When discussing innovation as an *outcome*, this paper refers to it as "innovation outcome," or simply "innovation," and when discussing innovation as a *process*, we refer to it as "the innovation process."

When discussing innovation, we also need to take into account what the object of our study is when thinking about our definitions. The discourse around strategic competition between the West and China contains several objects of study. Some researchers look at Western and Chinese economies as a whole and try to compare their innovativeness. Others study only parts of the economies, for example, the technological fields that are assessed to be critical for national security. Still others choose to study specifically the innovativeness of the respective countries' military complex. Since this report is drawing on a number of different researchers with different lenses, which sometimes are focused on defence and military matters, and sometimes take a broader view, it seems reasonable to use a broad definition of innovation, rather than one focused specifically on defence or military innovation.

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[14] OECD/Eurostat. *Oslo Manual 2018: Guidelines for Collecting, Reporting and Using Data on Innovation, 4th Edition*, The Measurement of Scientific, Technological and Innovation Activities (OECD Publishing, 2018): p. 20.

2.2 Innovation systems and the innovation process model

Creative and systematic work that seeks to increase and devise new applications of a community's stock of knowledge (i.e., to innovate) is known as research and experimental development (R&D).[15] However, not all innovation comes from systematic R&D. In many cases, innovation occurs sporadically from various kinds of learning processes that are part of everyday experiences and economic activity, such as learning-by-doing, learning-by-using, and learning-by-interacting.[16] In this way, innovation activities are *systemic*, in the sense that these learning experiences and the creation of new knowledge do not occur in a vacuum, but within a context of political, social, and economic institutions.

Innovation systems theory, pioneered in the early 1990s, has become a popular approach to understanding how interactions between actors and institutions influence innovative performance.[17] The innovation system concept has numerous definitions, but aims to emphasise the many different actors that are involved in the innovation process—including research organisations, commercial enterprises, and consumers, among many more—and how the web of interactions between them is crucial for innovation to take place.[18] Such interactions naturally occur in relation to R&D activity, as well as in everyday economic activities, including procurement, production, and marketing.[19] Innovation is not only a matter of technical expertise, but also depends largely on the organisational and social aspects of how innovative activities are conducted and distributed. In other words, the emphasis is on the circulation and accumulation of knowledge throughout society.[20]

Innovation systems theory also emphasises that innovation is not a linear process but an ongoing loop of feedback and experimentation within this interactive web of actors.[21] Innovation processes occur on local, regional, and global levels, where the network of actors is the unit of analysis. These networks can be sectoral, local, regional, or even transnational. However, one major strand of innovation-systems

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[15] OECD. *Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development*. The Measurement of Scientific, Technological and Innovation Activities (OECD Publishing, 2015): pp. 44–45.

[16] Charles Edquist. "Systems of Innovation Approaches—Their Emergence and Characteristics," in C. Edquist (ed.), *Systems of Innovation: Technologies, Institutions and Organizations* (Routledge, 1997): p 1–29.

[17] Mu, Rongping, Chen, Jin & Lyu, Rebecca Wenjing. The Development of Innovation Studies in China in Xiaolan Fu, Bruce McKern and Jin Chen (eds.). *The Oxford Handbook of China Innovation* (Oxford University Press, 2021): pp 73–89.

[18] (OECD). *National Innovation Systems* (1997): p. 9.

[19] Institutions and Organizations in Systems of Innovation in Charles Edquist (ed.). *Systems of Innovation: Technologies, Institutions and Organizations* (Routledge, 1997): p. 42.

[20] Mariana Mazzucato. *The Entrepreneurial State* (Demos, 2011): pp. 65–66.

[21] OECD/Eurostat. *Oslo Manual*, p. 45.

theory focuses on national-level innovation systems. National innovation-system (NIS)-theory recognises the nation-state as the primary arena for innovative activities.[22] In recent years, scholars have increasingly emphasised the role of the state in enabling innovation, for example providing leadership and investing in up-and-coming areas before market actors are willing to do so.[23]

Fundamentally, there are two sources of knowledge in all three types of R&D activity: external acquisition and internal creation. What constitutes "external" and "internal" is defined in relation to the systemic level of the innovation activity that is referred to. In terms of national innovation capabilities, the mix of external (foreign) and domestically produced new knowledge in innovation outcomes varies depending on the development level of a nation's economy and technological base. Countries in a technological catching-up stage are more reliant on foreign sources of knowledge, and generally tend to engage in varyingly creative modes of copying, imitation, and localised adaptation. As their innovative ability improves, in theory they eventually transition into original innovation activity, where the most common distinction is between incremental (limited improvements and updates of systems and processes that create novel outcomes) and radical (major technological breakthroughs) innovation.[24] Incremental innovation is the most basic and standardised form of innovation and occurs routinely as existing products and processes are redesigned or updated, introduced to new markets, etc. Radical innovation, on the other hand, requires innovation in several components or aspects all at once to produce transformational changes in a product or process applicable across many systems.

This imitation-to-innovation typology describes how the quality of national innovation outcomes can evolve over time, but says little about the innovation process itself. Despite the fact that innovation is an ongoing process, i.e. a continuous learning experience based on feedback and shaped by actor-network interactions, rather than a linear one, it can sometimes be useful to describe the different sequences of an innovation process. This is called an innovation process model. There are plenty of different ways to divide the stages of the innovation process. [25] This report uses a modified version of Horowitz and Pindyck's (2023) process model in order to analyse innovation.[26] The model describes military innovation

[22] Chris Freeman. The "National System of Innovation" in historical perspective. *Cambridge Journal of Economics.* 19:1 (1995): pp. 5–24.; Bengt-Åke Lundvall. *National Innovation Systems: Towards a Theory of Innovation and Interactive Learning* (Pinter Publishers*:* 1992).

[23] Mazzucato (2011).

[24] Tai Ming Cheung, William Lucyshyn, and John Rigilano. Th*e Role of Technology Transfers in China's Defense Technological and Industrial Development and the Implications for the United States* (Naval Postgraduate School, 2019).

[25] For a few different examples of innovation-process models see Jiwat Ram, David Corkindale, & Roger Tagg. Empirical Validation Of A Performance-Based Innovation Process Model: A Case Of ERP. *Journal of Computer Information Systems*. 56:2 (2016): pp. 116–126.

[26] Michael C. Horowitz & Shira Pindyck. What is a military innovation and why it matters. *Journal of Strategic Studies*. 46:1 (2022): pp. 100–101

within a military community, but with some minor adjustments their model can be applicable to a broader set of actors. They describe an innovation process model as containing three stages: invention, incubation, and implementation. For this report, we use the following definitions of the terms.

- *Invention* is the creation of a new idea or technology, or the use of an existing idea or technology in a new way to solve a problem.
- *Incubation* is the process of an invention's gaining status and influence throughout an organisation.
- *Implementation* is the process by which the invention is adopted and applied throughout the organisation.

In other words, in this model, innovation starts with a new idea or technology. The organisation then gradually becomes convinced that this innovation is superior to whatever idea/technology it replaces. Once the organisation has become convinced of this, it decides to adopt/apply the innovation throughout the organisation.

Horowitz also notes that after the implementation stage, innovations tend to spread to other organisations and gradually become established within the wider economic or military ecosystem. This phenomenon is known as *diffusion*, and is a central part of innovation.[27] Since Horowitz and Pindyck's model is designed to explain the process within a single military community, diffusion is not included in their model. However, other models that look at innovations from a more macroeconomic perspective often include diffusion.[28] An invention's successful integration and use in society is often viewed as more critical for long-term effects on technological, social, and economic change than the actual invention itself.[29] Jeffrey Ding states that taking note of indicators of diffusion is a better predictor of long-term growth than invention capacity is.[30] For this reason, we include diffusion in this report, using the following definition:

- *Diffusion* is the spread of the invention to other organisations or parts of the economy.

It is worth noting that diffusion is notoriously difficult to study given the number and complex arrangements of actors involved; the varying strength of linkages between them; and the transnational nature of innovations. Many innovations are

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[27] OECD/Eurostat. *Oslo Manual*, pp. 31–32.

[28] See for example Jean Hartley. Public and private features of innovation. In Stephen P. Osborne and Louise Brown (eds.). *Handbook of Innovation in Public Services* (Edward Elgar Publishing, 2013); Comin, & Hobijn. An Exploration of Technology Diffusion; see also Everett Rogers' work, *Diffusion Of Innovations* (Free Press, 1962), which is usually credited with first developing diffusion theory.

[29] Jeffrey Ding. The rise and fall of technological leadership: general-purpose technology diffusion and economic power transitions. *International Studies Quarterly*. 68:2 (2024).

[30] Jeffrey Ding. The diffusion deficit in scientific and technological power: re-assessing China's rise. *Review of International Political Economy*. 31:1 (2024): pp. 173–198.

shared across national boundaries, and, in the case of technology innovations, nations typically import as much, if not more, new technology than they innovate themselves, which makes diffusion tricky to measure in the context of national innovation.[31]

Moreover, the time taken to diffuse new products and processes to substantial economic effect (known as the *adoption lag*) is often long. According to one study on the diffusion of new technologies in production methods, the adoption lag for various significant 20th century inventions was on average 5–16 years.[32] Even though this lag appears to be getting shorter and shorter with the advent of digital technologies, the nonetheless years-long timeframes and organic patterns of diffusion pose significant challenges to understanding how contemporary innovations spread and consolidate. Scholars have pointed to the difficulty of understanding these processes other than in retrospective.[33] For military innovation, civilian or dual-use technologies developed according to commercial incentives tend to spread more quickly than technologies with purely military uses, though even this remains far from an overnight occurrence.[34]

The speed of adoption of innovations is influenced by a number of factors, including organisational leadership, how well the innovation fits with the organisation's norms and values, and how motivated the organisation is to adopt changes.[35] Looking at military innovations, Goldman and Ross note that the strategic necessity for a state to be able to compete in the international system can be a powerful driver for adopting innovation. They also observe, however, that if an innovation does not fit into the existing culture or is seen as illegitimate within a social system, the innovation is less likely to be implemented.[36] The impact of organisational culture and values, and the likelihood of adopting innovations, highlight the importance of the incubation and implementation steps of the innovation process.

Since the discourse around strategic competition between the West and China analyses the innovation capacity of not only the respective militaries, but also across their entire economies, it makes sense for this report to include diffusion as part of the model. The innovation process model that this paper uses thus contains the following stages: **invention—incubation—implementation—diffusion.** The

[31] David E. H.Edgerton. The contradictions of techno-nationalism and techno-globalism: A historical perspective. *New Global Studies*. 1:1 (2007): p. 8.

[32] Diego Comin and Bart Hobijn. An Exploration of Technology Diffusion. *American Economic Review.* 100:5 (2010): p. 2048.

[33] Schulte. Innovation and control, p. 31.

[34] Michael C. Horowitz. Artificial Intelligence, International Competition, and the Balance of Power. *Texas National Security Review*. 1:3 (2018): pp. 36–57.

[35] Jennifer P.Wisdom, Ka Ho Brian Chor, Kimberly E. Hoagwood, et al. Innovation Adoption: A Review of Theories and Constructs. *Adm Policy Ment Health* 41, 480–502 (2014). https://doi.org/10.1007/s10488-013-0486-4

[36] Emily O. Goldman and Leslie C. Eliason, eds., *The Diffusion of Military Technology and Ideas* (Stanford, CA: Stanford University Press, 2003). pp 373–381

model is based on Horowitz and Pindyck's work, but uses the modified definitions mentioned above to allow for the study of a broader set of actors.

2.3 Measuring national innovation systems

As shown above, innovation is a wide concept that may refer to increased knowledge as well as improved products and processes across a broad range of productive activities. However, a central and distinct type of innovation is innovation in science and technology (S&T): the creation of new (or advancements in) scientific knowledge and technological capabilities through R&D and technological learning. This is the primary innovation type that we refer to in this report. For the past sixty years, economists have recognised innovation, or more specifically, technological change, as a result of S&T innovation, as a major source of economic growth.[37] In particular, S&T innovation is integral to sustained long-term growth. A central tenet, that a developing country *must* innovate to avoid economic stagnation once it reaches mid-income status, is known as the "middle-income trap."[38] The reliance on imports and imitation of products and processes developed elsewhere is a good start, yet insufficient for sustained growth, since products will eventually lose global competitiveness when newer, cheaper, and better options enter the market.[39]

When studying the question of strategic competition, our interest in innovative capacity is its relation to national power. As described above, innovative capacity generates increased economic resources, and thus economic power. Economic power is not the only form of power, however. Power can also be derived from military resources or from the quality of a country's institutions, for example.[40] However, authoritative theories of international relations argue that economic resources are the foundation of many other types of national power, including military strength.[41] Thus, innovative capacity becomes an important tool for countries that wish to increase their overall national power, even within fields where the innovations in question have no direct link to an increase in military capability. The authors of this report tend to agree with this view of national power, which is why we chose to include and compare reports studying broader economic

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[37] See Edquist 1997; Philippe Aghion, & Peter Howitt, A model of growth through creative destruction, *Econometrica,* 60 (1992): pp. 323–351; Elhanan Helpman & Gene M. Grossman. *Innovation and Growth in the Global Economy* (MIT Press, 1993): pp. 43–111.

[38] Indermit S. Gill & Homi Kharas. *An East Asian renaissance: Ideas for economic growth (Vol. 1 of 2) (English)* (World Bank, 2007): pp. 17–18 and 123–183; Homi Kharas & Harinder Kohli. What is the Middle Income Trap, Why do Countries Fall into It, and How Can It be Avoided? *Global Journal of Emerging Market Economies*. 3:3 (2011).

[39] Middle-income claptrap—Do countries get "trapped" between poverty and prosperity? *The Economist* (2013-02-16).

[40] Gregory F. Treverton, Seth G. Jones. "Measuring National Power," RAND National Security and Research Division, 2005

[41] Andrew B. Kennedy & Darren J. Lim. The innovation imperative: technology and US-China rivalry in the twenty-first century. *International Affairs.* 94:3 (2018): pp. 554–572.

resources in addition to comparisons more directly related to military power in the meta-analysis below.

Following the emergence of S&T innovation as a core driver of wealth and power in modern political economic thought, governments' need to be able to measure whether their innovation capacity has increased. A government's decision to invest in national S&T innovation progress is a political one and usually requires substantial resource allocation to implement, since the production of new knowledge is an inherently expensive (and often financially and politically risky) process. Depending on the industrial sector and the state's level of innovation prioritisation, efforts to promote innovation activities divert and redistribute material and financial resources away from the provision of welfare and other public goods to varying degrees. The development of innovation measures thus arose not only for practical reasons—policymakers' need for statistics to monitor, manage, and assess the resources invested in R&D to advance S&T innovation—but also for political reasons, to make visible the government's performance and justify to citizens the high value of innovation payoffs.[42] Given the implications of S&T maturity for national power and international prestige, these statistics are also commonly used to compare national S&T innovation progress across countries.[43]

Innovation activities and the kind of structural change that may result from it are inherently tricky to quantify. For this reason, innovation measurements primarily focus on aspects related to a nation's S&T base and R&D activities and generally do not attempt to measure the overall impact or change inspired by a given invention or innovation. For international comparability, national-level innovation measurements often focus on measurements of R&D and S&T infrastructure, though the OECD has developed measures for non-R&D innovation activities (such as training and the acquisition of external knowledge) at the enterprise level as well.[44]

Despite extensive research on what drives some nations to produce more innovation output, a general theory remains elusive. Even though the field has long perceived "soft" input variables such as governance norms as the primary determinants of a nation's long-term innovative potential, recent statistical analysis by Mark Zachary Taylor shows that the correlation is not always positive and accounts only for some variation in national innovation rates.[45] This indicates that it is not the specific types of institutions per se but rather the effect they have on mitigating the risks and costs associated with knowledge production, combined with a favourable resource base, that determines a country's chances of sustained

[42] Benoît Godin. *Measurement and Statistics on Science and Technology: 1920 to the present* (Routledge, 2005): pp. 7–9, 296–297 & 323.
[43] Edgerton. The contradictions of techno-nationalism and techno-globalism.
[44] OECD. *Oslo Manual,* pp. 89–104.
[45] Taylor. *The Politics of Innovation*, pp. 107–139 & 156–179.

S&T innovation success. In sum, states produce a lot of data on their innovation activity. As previously mentioned, the power dimension of S&T innovation capacity means there is an inherently comparative (and competitive) aspect to national innovation activities. To this end, several broad indexes benchmark innovativeness between countries, including the Global Innovation Index, the European Innovation Scoreboard, and the Global Competitiveness Index.[46]

Despite the fact that innovation indicator values should not primarily be read normatively ("high is good, and low is bad"), the result is often taken as a reflection of a state's overall technological competitiveness, and as signal of status and prestige among the knowledge economies of the world. While rankings serve important purposes in disseminating information and conferring status, studies also suggest that rankings are engines of anxiety that reshape the power dynamics in the sector they evaluate and pressure organisations to focus on improving their relative position, rather than striving to achieve their own strategic goals.[47] The OECD has warned that comparative statistics are "not good yardsticks for science planning," and, interpreted uncritically, may lead countries to spend more on R&D than they should or can afford to for prestige reasons.[48] Rankings can even inhibit innovation by encouraging conformity in R&D methodologies as lower-ranked entities seek to copy top-ranked counterparts. Moreover, rankings-induced expectations can also pressure stakeholders to engage in immoral or even illegal behaviours to reach high targets.[49] These aspects are important to keep in mind going into the following chapter, which presents a meta-analysis of comparative studies of innovative capacity.

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[46] See World Intellectual Property Organization's (WIPO) *Global Innovation Index;* the European Commission Directorate-General for Research and Innovation's *European Innovation Scoreboard*; and World Economic Forum's *Global Competitiveness Report.*

[47] Violina P. Rindova, Luis L. Martins, Santosh B. Srinivas, & David Chandler. The Good, the Bad, and the Ugly of Organizational Rankings: A Multidisciplinary Review of the Literature and Directions for Future Research, *Journal of Management*. 44:6 (2017).

[48] Godin. Measurement and Statistics on Science and Technology: pp. 7–9.

[49] Rindova et al. The Good, the Bad, and the Ugly of Organizational Rankings, p. 14.

3 Comparing national innovation systems in China and the West

3.1 Introduction

The question of how well the Chinese innovation system measures up against the West, in particular the United States, is a topic frequently discussed in foreign policy circles.[50] Proponents of such comparisons argue that understanding Western and Chinese innovation capabilities may help us to understand both how large or small the innovation capability gap really is, predict how the gap may develop in the future, and identify weaknesses in the Western innovation system that may then be corrected. This in turn may help to ensure a continued Western technological advantage in the strategic competition between China and the West.

Comparing the Western and Chinese innovation systems can be done both qualitatively and quantitatively. Cheung and Mahnken have written a notable qualitative report that touches on the present subject. Their report presents a qualitative net assessment of the respective strengths and weaknesses of US and Chinese techno-security systems.[51] Rather than assessing the nations' current innovation rate or innovative quality, the report compares each nation's political, institutional, and ideational preconditions for succeeding in long-term technological competition. The authors find that both countries have competitive advantages in some key factors and disadvantages in others. They identify governance quality and the maturity of their respective models as critical to their long-term success. The structure and organisation of the US system seems superior, as it enjoys better linkages between public-private actors. In comparison, China's approach to S&T governance suffers from bureaucratic fragmentation, corruption, and a compliance framework centred on penalties rather than incentives. These structural ailments put Beijing's system at a disadvantage to the US bottom-up, positive-incentive model, which, while old, is tried-and-tested and suited for making consistent progress. The report concludes that the outcome of their strategic competition will ultimately depend on each country's ability to harness their strengths while mitigating weaknesses and their responsiveness to new developments in the security and technology domains.

The quantitative studies, however, are arguably more influential than the qualitative studies. They tend to have a bigger impact since they allow researchers and

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[50] C.f. China and the West are in a race to foster innovation. *The Economist* (2022-10-13); Edmund S. Phelps. Will China out-innovate the West? *Project Syndicate* (2018-03-05).

[51] Tai Ming Cheung and Thomas G. Mahnken. *The decisive decade: United States-China competition in defense innovation and defense industrial policy in and beyond the 2020s* (Center for Strategic and Budgetary Assessments, 2023).

policymakers to compare relative changes between the actors over time.[52] When conducting a quantitative analysis of something as intangible as innovation, however, correctly discerning what conclusions can be drawn based on the report's chosen variables can be difficult, especially if you are a policymaker who only has time to read a summary of the report. Might there be aspects of the innovation process that are missed when turning a broad concept into specific variables? And what would that imply for future analyses of the Chinese and Western innovation systems?

The section below looks at how quantitative studies that have been influential in this field have chosen to measure innovation. By analysing the variables used to measure innovation, this meta-analysis reflects on the possibilities and limits of comparing innovation capability.

Three different research organisations have recently published quantitative comparisons of Chinese and Western relative innovativeness through the lens of strategic competition. The organisations are the Australian Strategic Policy Institute (ASPI), the Information Technology and Innovation Foundation (ITIF) and RAND Corporation (RAND). All three have chosen to compare the innovativeness of the innovation systems by considering certain quantitative variables over time. RAND and ITIF compare China and the US, whereas ASPI compares China to a broader set of countries in and beyond the West. The objects of study thus differ slightly, but this should not matter in the present study, since our goal is to analyse their methodologies rather than their results.

Conducting a meta-analysis of these reports, this section describes what variables they used to compare innovation capability, and discusses the possibilities and limits of quantitative analysis when comparing innovation capability. More specifically, this section first provides a short summary of the contents of each report. This is followed by a consideration of each variable that the reports use to compare innovation systems in the US and China, and then sorts the variables into a chart to provide an overview of how the reports measure innovation. The chart showing how each report measures innovation allows us to proceed to compare the reports to each other and to the theoretical definitions above, thus illustrating the strengths and weaknesses of using certain variables as a way to measure innovation.

[52] The most influential study is probably ASPI's, which has received international media attention. C.f. Daniel Hurst. China leading US in technology race in all but a few fields, thinktank finds. *The Guardian* (2023-03-02); China leads US in global competition for key emerging technology, study says. *Reuters* (2023-03-02); China beating West in race for critical technologies, report says. *Al Jazeera* (2023-03-03).

3.2 Summary of the reports

ASPI's Critical Technology Tracker

One of the most well-known attempts to describe the growing strength of the Chinese innovation system is ASPI's Critical Technology Tracker, which was first published in 2023, followed by an updated version in 2024.[53] The Technology Tracker measures the number of cited papers, talent flows, and patents within technological fields that ASPI has deemed critical to strategic competition to determine the relative innovative strength between China and Western countries.

ASPI concludes that China is the leading country in 57 out of 64 analysed technological fields, based on the output of the top ten percent of most-cited papers in the field.[54] The 2023 ASPI publication cited here also looks at talent flows between countries within critical fields. In this respect, ASPI finds that the West still attracts more talent from abroad, whereas China experiences a net drain on talent. The report warns, however, that access to top talent is becoming more competitive.[55]

ASPI also evaluates the monopoly risk of the 64 technologies. For a technology to be ranked as "at high risk of monopoly," at least 8 of the top 10 institutions (again, based on highly cited papers) have to be located in a single country, and that country has to be publishing at least 3 times as many highly cited papers as the second-best country. ASPI ranks 24 technologies as at high risk of being monopolised by China, including nanoscale materials, electric batteries, and advanced radio-frequency communications (including 5G and 6G).[56] ASPI concludes from this that China may gain a stranglehold on certain critical technologies in the immediate term, and shift the global power balance in its favour in the longer term.[57]

ITIF: Wake up, America

The Information Technology and Innovation Foundation released a report in 2022 called "Wake Up, America: China Is Overtaking the United States in Innovation Output."[58] The report uses a methodology that divides innovation into three subgroups: innovation input, innovation output, and innovation outcomes.

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[53] Jamie Gaida, Jennifer Wong-Leung, Stephan Robin & Danielle Cave. *ASPI's Critical Technology Tracker—The global race for future power* (Australian Strategic Policy Institute, 2023); Jennifer Wong-Leung, Stephan Robin & Danielle Cave (2024). *ASPI's two-decade Critical Technology Tracker—The rewards of long-term research investment* (Australian Strategic Policy Institute, 2024).

[54] Wong-Leung et al. *ASPI's two-decade Critical Technology Tracker,* p. 4.

[55] Gaida et al. *ASPI's Critical Technology Tracker*, p. 1.

[56] Wong-Leung et al. *ASPI's two-decade Critical Technology Tracker,* p. 5.

[57] Gaida et al. *ASPI's Critical Technology Tracker,* pp. 1–2.

[58] Ian Clay & Robert Atkinson. *Wake Up, America: China Is Overtaking the United States in Innovation Output* (Information Technology & Innovation Foundation, 2022).

ITIF defines innovation input as the resources and institutions that are meant to contribute to the economy's stock of knowledge. Examples of innovation input are R&D investments in a country, or the education level of the country's population.

Innovation output is the new knowledge created by the inputs. Examples of innovation output are the number of patents a country produces, or the number of highly cited academic papers published by a country's scientists.

Innovation outcomes are the effects that the new knowledge leads to, for example, in changes in production or adoption of new technologies. Examples of innovation outcomes are the level of robotisation in a country's economy, or the complexity of a country's economy, which is measured by studying what kinds of products a country is exporting.[59]

By measuring the selected variables, ITIF concludes that during the last decade China has gained ground relative to the US in all three categories of innovation. However, the bulk of China's progress was in the category of innovation output, where China now publishes more academic articles and grants more international patent families than the US. A comparison of intellectual property receipts between the countries indicates that Chinese patents are still much less valuable than US ones. However, the value of Chinese intellectual property receipts relative to the US has increased from 1 percent to 8 percent from 2010 to 2020, indicating that China is catching up quickly.[60] Looking at innovation outcomes, however, the results are more mixed. China became more specialised relative to the US in some areas, such as pharmaceutical manufacturing, but became relatively less so in other areas, such as computer programming. Overall, China's economic complexity did close in on the US, however. China has also taken the lead in high-performance computing, and is now the country that controls the greatest number of supercomputers (although the US still leads in total computing power among supercomputers).[61]

RAND: Comparative Analysis of US and PRC Efforts to Advance Critical Military Technology

RAND's report aims to compare the tools used by China and the US to advance their military technology. To do this, RAND separates the metrics it wishes to study into three categories: research, development, and fielding. Research is defined as the undertaking of scientific investigation with the objective of producing new knowledge. Examples of research variables are scientific publications, and the number of organised conferences within a field.

Development is defined as a process of using existing knowledge to produce a useful new technology or improve an existing one. Examples of development

[59] Ibid, p. 13.
[60] Ibid, pp. 44–45.
[61] Ibid, pp. 55–56.

variables are patent-grant output, and the number and description of a country's military development programs.

Fielding is defined as the deployment of military capabilities using the focal technology. Examples of fielding variables are the quantity and value of a country's foreign military sales, and the number and key technical specifications of a country's completed systems that leverage a focal critical technology area. [62]

RAND has chosen not to make the results of its report public, thus, we only have access to the methodology.

3.3 What do the different reports evaluate?

This section presents a framework, which lets us compare the methodologies of the reports to each other, and to the theoretical models and definitions presented above. This framework uses the following chart for comparisons:

Variable type	Category	Studied by	Innovation stage

A more expansive explanation of the chart follows below, but here follows a brief summary. ***Variable type*** gives an overview of which types of variables the reports use to measure innovation. ***Category*** sorts the variable types into larger categories to help the reader see patterns among the variables. ***Studied by*** simply refers to which of the three reports included this specific variable type in their methodology. ***Innovation stage*** tries to determine what stage of the innovation process is being measured, by classifying the variable type according to the modified version of Horowitz and Pindyck's innovation-process model, presented above. Thus, each variable type is classified as either invention, incubation, implementation, or diffusion.

In order to create the chart, this study first listed every variable in each report that focused on the innovation system as a whole. ASPI and ITIF also studied specific technological fields to see how the countries measured up against each other within each field. ITIF also studied subgroups within a population, for example the education level of 20–29-year-olds. Such variables focusing on specific technologies or subgroups have been excluded from this comparison, as the goal is to compare the reports' methodology of the total innovation capacity of their respecttive objects of study.

[62] Sarah Harting, Daniel Gonzales, Michael J. Mazarr, and Jon Schmid, *Comparative Analysis of U.S. and PRC Efforts to Advance Critical Military Technology: Volume 1, Analytic Approach for Conducting Comparative Technology Assessments* (RAND Corporation, 2024): pp. 53–56.

Once all the relevant variables from the reports had been listed, the next step was to match overlapping variables with each other. No variable was exactly the same between the reports, but sometimes the variables were similar enough that it made sense to classify them as functionally the same. For example, ASPI counted the number of top institutions in a country by looking at how many institutions each country had that were among the top 10–20 highest performing institutions based on highly cited papers. ITIF also looked at the number of top institutions in a country, but did it based on the Shanghai Ranking (Academic Ranking of World Universities, ARWU). Thus, both ASPI and ITIF are trying to measure the number of top academic institutions in a country, even if they are measuring it in different ways. This report therefore has chosen to pair these two variables together, which means that they are given the same ***variable type*** in the chart below. The variable type is not the exact variable used by each report, but rather an attempt to summarise and cluster the variables. In this case, ASPI and ITIFs variables are classified with the variable type "top institutions in a country." Describing the classification process for each variable becomes far too expansive for this report, but in the appendix, the interested reader can find listed every variable used by each of the reports, and what variable type the variable was classified as.

Once the variables had been sorted into variable types, the next step was to categorise the variable types to give a better overview of what was being studied. The clustering of variables gave us 20 different variable types. But most of them could be clustered again into various categories. For example, both the variable types "patents granted in relevant fields" and "patent receipts" can be clustered into a common category simply called "patents." Similarly, both the variable type "researcher talent flows" and "access to researchers" can be clustered into a common category, together with "population education level," which this study calls "human capital".

Once the data on variable types, categories, and research organisations have all been inserted, the chart looks like this (see table 1 below):

Table 1. Categorisation of variables.

#	Variable type	Category	Studied by	Innovation stage
1	Top institutions in a country	Institutions	ASPI, ITIF, RAND	
2	Top firms in critical fields	Institutions	ITIF, RAND	
3	Research centrality	Institutions	RAND	
4	R&D expenditure and investment	Economic resources	ITIF, RAND	
5	Access to venture capital investment by country	Economic resources	ITIF	
6	Quantity and quality of published papers	Academic papers	ASPI, ITIF, RAND	
7	Patents granted in relevant fields	Patents	ITIF, RAND	
8	Patent receipts	Patents	ITIF	
9	Researcher talent flows	Human capital	ASPI	
10	Access to researchers	Human capital	ITIF, RAND	
11	Population education level	Human capital	ITIF	
12	Production in and export from advanced industries	High-tech economic output	ITIF	
13	Economic complexity	High-tech economic output	ITIF	
14	Testing infrastructure	Infrastructure	ITIF, RAND	
15	Robotization	Infrastructure	ITIF	
16	Cellphone and Broadband access	Infrastructure	ITIF	
17	Cybersecurity	Composite variable	ITIF	
18	Fielded advanced military systems	Advanced weapons production	RAND	
19	Weapons exports	Advanced weapons production	RAND	
20	Technology transition (qualitative variable)	Advanced weapons production	RAND	

Innovation stages

We now proceed to classifying the variables according to their innovation stage. As mentioned in the theory section, going from an initial innovation idea to a developed and widely used product is a long journey that contains several stages. Identifying which stage the variables correspond to gives us a clearer insight into what part of the innovation process current studies usually measure. This is important for two reasons: firstly, because previous literature indicates that some stages may be more important than others when it comes to predicting the economic impact of innovation;[63] secondly, because it may help clarify whether some stages of the innovation process are receiving too much or too little attention in the current discourse concerning Chinese-Western strategic competition. This in turn may help inform future studies.

The classification is done by comparing the different categories that the studies themselves use to separate their different variables with the innovation process stages based on Horowitz and Pindyck's work. Occasionally, this study argues that a certain variable should be classified differently than what would be suggested by matching its assigned category against the innovation process stages. In each such case, this study makes a separate argument as to why we think that a different classification is appropriate.

Classifying the innovation stages requires us to look back at the definitions descry-bed in the theory section. The modified model based on Horowitz and Pindyck defines the innovation stages as follows:

- *Invention* is the creation of a new idea or technology or the use of an existing idea or technology in a new way to solve a problem.
- *Incubation* is an invention gaining status and influence throughout an organisation.
- *Implementation* is the process by which the invention is adopted and applied throughout an organisation.
- *Diffusion* is the spread of the invention to other organisations or parts of the economy.

Now let us compare the definitions above with the categories used by ITIF. ITIF splits its innovation variables into three categories: innovation input, innovation output, and innovation outcomes. ITIF defines innovation input as the resources and institutions meant to contribute to the economy's stock of knowledge. In other words, the goal of the actors who are generating innovation input is to produce new ideas or inventions. Thus, ITIF's variables that fall under its definition of

[63] Ding. The diffusion deficit in scientific and technological power.

innovation input should be considered to correspond to the innovation stage of invention. This includes variable types 1, 2, 4, 5, 10, and 11.

ITIF defines innovation output as the new knowledge created by the inputs. It is relatively common in the innovation literature to distinguish between inputs, which are resources that can generate knowledge, and output, which is the knowledge generated. For the purpose of this study, however, if we look at the definitions above, innovation output also best matches the invention stage, since the innovation output focuses on the generation of new ideas or technologies. Thus, variable types 6, 7, and 8 should be classified as invention.

ITIF further defines innovation outcomes as the effects that the new knowledge leads to, in, for example, changes in production or the adoption of new technologies. This seems to best fit the description of diffusion in Horowitz and Pindyck's model, meaning that the ITIF variables in variable types 12, 13, 14, 15, 16, and 17 should be counted as diffusion. However, we argue that variable type 13, Testing Infrastructure, should instead be classified as invention. Testing Infrastructure refers to high-tech infrastructure available to conduct studies at the very frontier of research. Examples of such infrastructure are super computers and large hadron colliders. Testing Infrastructure constitutes a resource aimed at helping to produce new knowledge. While the testing infrastructure itself is also a result of the diffusion of knowledge and resources, its value lies in the potential production of new knowledge. This study therefore classifies it as invention.

As for RAND's study, they divide their innovation variables into the categories research, development, and fielding. RAND defines research as the undertaking of scientific investigation with the objective of producing new knowledge. This definition is very similar to ITIF's definition of innovation input, and seems to fit well with the definition of invention presented above, meaning that RAND's variables in variable types 1, 3, 6, and 10 are classified as invention.

RAND defines development as a process of using existing knowledge to produce a new useful technology or improve on existing technology. This again falls under the invention stage, as the goal remains to produce a new idea or technology. Thus, RAND's variables under variable types 2, 4, 7, and 13 should be classified as invention.

RAND defines fielding as the deployment of military capabilities using the focal technology. This best matches Horowitz and Pindyck's description of implementation, which they understand as the process whereby the invention is adopted and applied throughout the organization. Thus, RAND's variables under variable types 18, 19 and 20, should be listed as implementation. However, this study argues that variable type 20, Technology Transition, should instead be classified as incubation. Technology Transition, unlike almost every other variable, is a qualitative variable,[64] and measures "a country's ability to turn development activity into fielded military systems." RAND writes very little about this in its report, but in personal communication with the authors it has specified that this might, for example, involve describing the interactions and relationships between the military and defence contractors. The ability to turn development activity into fielded systems seems to match Horowitz and Pindyck's description of incubation, which focuses on the invention's gaining status and influence throughout the organisation. Therefore, we classify variable type 20 as incubation.

ASPI only studied three variable types: top institutions in a country, academic papers, and researcher talent flows. Top institutions in a country and academic papers were also measured by both RAND and ITIF and in both cases the sorting that they conducted led this study to classify those variable types as invention. Classifying ASPI's variables in the same way seems reasonable. The variable of researcher talent flows has only been measured by ASPI, but given that it is concerned with access to research talent, whose goal is to generate new knowledge, ideas, and technologies, classifying research talent flows under invention also makes sense.

Once the classification is complete, the chart is as follows (see table 2 below):

Table 2: Classification of variables into innovation stages.

#	Variable type	Category	Studied by	Innovation stage
1	Top institutions in a country	Institutions	ASPI ITIF RAND	Invention
2	Top firms in critical fields	Institutions	ITIF RAND	Invention
3	Research centrality	Institutions	RAND	Invention
4	R&D expenditure and investment	Economic resources	ITIFRAND	Invention
5	Access to venture capital investment by country	Economic resources	ITIF	Invention
6	Quantity and quality of published papers	Academic papers	ASPIITIF RAND	Invention
7	Patents granted in relevant fields	Patents	ITIFRAND	Invention
8	Patent receipts	Patents	ITIF	Invention
9	Researcher talent flows	Human capital	ASPI	Invention
10	Access to researchers	Human capital	ITIF RAND	Invention

[64] RAND also uses a qualitative variable to measure top firms in critical fields and uses one qualitative and two quantitative variables to measure R&D expenditure and investment. All other variable types are only measured with quantitative variables.

11	Population education level	Human capital	ITIF	Invention
12	Production in and export from advanced industries	High-tech economic output	ITIF	Diffusion
13	Economic complexity	High-tech economic output	ITIF	Diffusion
14	Testing infrastructure	Infrastructure	ITIF RAND	invention
15	Robotisation	Infrastructure	ITIF	Diffusion
16	Cell phone and broadband access	Infrastructure	ITIF	Diffusion
17	Cybersecurity	Composite variable	ITIF	Diffusion
18	Fielded advanced military systems	Advanced weapons production	RAND	Implementation
19	Weapons exports	Advanced weapons production	RAND	Implementation
20	Technology transition (qualitative variable)	Advanced weapons production	RAND	Incubation

Analysis

In analysing the chart, a few things become apparent. Firstly, most variables that measure innovation specifically measure the invention stage. Of the 20 variable types studied by the three reports, 12 primarily measure invention. The variables used to measure invention—include the counting of patents, academic publications and citations, as well as investments in R&D—are among the most popular ways of comparing innovation capacity within the broader strategic competition discourse. The invention variable types also span six different categories, meaning that there is a diverse range of options available for whoever wants to measure invention.

Conversely, the other stages of the innovation cycle appear harder to measure. Nevertheless, ITIF attempts to measure diffusion. The variable types that measure diffusion include production in, and export from, advanced industries, economic complexity, robotisation, cell phone and broadband access, and cybersecurity. The variable types for diffusion are sometimes harder to measure (economic complexity and robotisation) and occasionally use proxies, whose accuracy can be discussed. For example, it is not evident whether broadband access is a good measure of technological diffusion across the economy.

A state's capacity for innovation may correlate with its capacity to absorb and diffuse new technologies, but this is not automatically the case. Ding argues that China's diffusion capacity is significantly weaker than its capacity to generate inventions.[65] Tai Ming Cheung concurs with the idea that diffusion is essential for China's military capability development, pointing to historical examples of weapons development.[66] Thus, it still seems worthwhile to attempt to measure diffusion even though it poses measurability challenges, since it may be a more useful predictor of future economic development. This is a potential weakness of ASPI's report, since it relies solely on variables that primarily study invention, which means that it risks overestimating Chinese innovation capacity. The most recent update of ASPI's report takes note of this risk, but still maintains the goal of providing insights into states' future potential S&T capacity.[67]

Only RAND studied implementation and incubation. It studied these two stages by focusing specifically on the armed forces of China and the US. The choice of variables illustrates the difficulty of measuring incubation or implementation at a macro level. Finding a variable to measure how well companies in general implement or incubate new inventions only seems to be done indirectly through measuring diffusion. When studying implementation, RAND measured fielded, advanced military systems and weapons exports. The latter can be counted quite easily, whereas the former requires a qualitative assessment as well as a quantitative analysis to properly measure.

To measure incubation, RAND has only one variable, and it is a qualitative one, illustrating again the difficulty of measuring incubation and implementation quantitatively. This seems to indicate that studies that use only quantitative variables to compare innovation capacity will have a hard time capturing the incubation and implementation aspects of the innovation process in their measurements. This in turn means that the armed forces' ability and efficiency in transforming new inventions into warfighting capability largely remains a black box, beyond the scope of what can be captured through quantitative studies. Studies of the current military force structure will of course give a snapshot of what a country's military innovation system has produced so far. But this provides limited understanding of the strengths and weaknesses of a military organisation in relation to incubation and implementation of innovations, which will impact the speed and efficiency with which the country can turn inventions into warfighting capability going forward.

Considering all of this, it seems clear that quantitative studies have an important role to fill for scholars and policymakers who study strategic competition. There are plenty of possible variables to study when looking at invention and also, to some extent, diffusion. It is important to remember, however, that the stages do not have to be correlated. A high invention capacity does not automatically translate into increased warfighting capability or higher economic growth. Such

[65] Ding. The diffusion deficit in scientific and technological power.

[66] Tai Ming Cheung. Innovation in China's Defense Technology Base: Foreign Technology and Military Capabilities. *Journal of Strategic Studies*. 39:5-6 (2016): pp. 728–76.

[67] Wong-Leung et al. *ASPI's two-decade Critical Technology Tracker,* p. 6.

an interpretation may lead us to overestimate China's innovative capacity. Therefore, an approach that considers all aspects of the innovation cycle is preferable when possible. Capturing the incubation and implementation stages may require other methods, however, and studying the implementation and incubation of a military such as China's will always be a challenge, given the difficulty of accessing information. Still, we should not ignore these stages. Scholarship suggests that how militaries use a technology can be more important than the technological innovation itself in altering or affecting the balance of power, thus once again emphasising the importance of how a technology is incubated and implemented.[68] Developing the ways in which we study incubation and implementation will be an important contribution to the literature on strategic competition going forward.

[68] Michael C. Horowitz. Artificial Intelligence, International Competition, and the Balance of Power - *Texas National Security Review*. 1:3 (2018): pp. 36–57.

4 Science and Technology in Governance and Policy

The Chinese Communist Party (CCP) has used S&T policies to boost economic development, strengthen its military power, and vie for global influence since the 20th century. In order to understand what Chinese decision-makers want to achieve by investing in innovation and why, we must consider the historical and ideational context in which current policy ambitions are set. Starting from a historical review, this chapter examines the connection between China's national power interests and its S&T governance. This should prove helpful to understanding the playing field on which contemporary geopolitical rivalries unfold, as well as providing context for interpreting China's innovation characteristics and S&T policies.

4.1 Science, national power, and the great rejuvenation

Before delving into how the CCP uses science and technology to grow the PRC's national power, it is important to understand the historical narratives in which China's concept of power is rooted. Fundamental to China's modern political culture is the understanding that Western powers oppressed imperial China into subordination starting from the mid-19th century. For millennia, China prided itself on being the world's technological centre, having invented paper, printing, gunpowder, and the compass, alongside improvements in agriculture and medicine. [69] Furthermore, the elite continually gained confidence from military successes, overall making the emperor disinclined to look outward for new technologies (and risk introducing harmful ideological influences).[70] In 1793, the Qianlong emperor turned down offers from the British Empire to set up trade relations, stating "[w]e possess all things… and have no use for your country's manufactures."[71]

Yet, overwhelming military defeat in the 19th century exposed the Qing dynasty's technological stagnation. Modern history-writing in China construes the 110 years from the First Opium War (1839–42) to the founding of the PRC in 1949 as the "century of humiliation": a shameful and traumatic juncture in history when a

[69] Jin Guantao, Fan Hongye & Liu Qingfeng. "The Structure of Science and Technology in History: on the Factors Delaying the Development of Science and Technology in China in Comparison with the West Since the 17th Century." In Fan Dainian & Robert S. Cohen (eds.) *Chinese Studies in the History and Philosophy of Science and Technology.* (Kluwer Academic Publishers, 1996): pp. 137–164; Patricia Buckley Ebrey. *Cambridge Illustrated History: China.* 2nd ed. (Cambridge University Press, 2010).

[70] Joanna Waley-Cohen. China and Western Technology in the Late Eighteenth Century. *The American Historical Review*. 98:5. (1993).

[71] Buckley Ebrey. *Cambridge Illustrated History: China*, pp. 234–239.

series of misfortunes caused the downfall of imperial China and decades of political upheaval.[72] The breakdown of the imperial order violently altered the way that the Chinese people viewed their nation and its place in the world: from morally and culturally superior to underdeveloped in relation to the industrialised powers. Yet, modern narratives pin blame for the humiliation not only on foreign imperialism, but also on incompetent and corrupt rulers who failed to keep up with the times.[73] This reading of history emerged in the late 1800s and characterised cultural and academic debate throughout the 20th century.[74] Contemporary discourses presented the Qing dynasty's inferior political, social, and philosophical traditions, its "lack of science," and refusal to adopt Western technologies such as steam and electricity as critical factors in its downfall into poverty and weakness.[75] Meanwhile, the rise of Japan showed that technological revolutions create pathways to power. These interpretations laid the groundwork for the view on strategic competition in present-day Chinese political imaginaries.

Consequently, S&T became a central element of the political agenda. Although the development of Chinese science was delayed by the political turbulence of the Republican and Civil War eras, the ideal of saving the nation through science and technology (*kexue jiuguo*) resonated clearly with the CCP's vision of national rejuvenation, i.e. the restoration of China's lost wealth, power, and status in international affairs. Chen Duxiu, co-founder of the CCP, wrote in 1919 that only by pairing political reform with science could his generation "save China from all of its political, moral, intellectual, and spiritual darkness."[76] Throughout the 1950s, CCP writings propagated ideas about technology as a fundamental element of industrial competitiveness, international standing, and economic power.[77]

Upon proclaiming the People's Republic, Mao Zedong (1949–1976) initiated extensive industrialisation efforts to address the country's need for military and economic recovery after decades of war. The CCP saw technological self-reliance (*zili gengsheng*) as key to ensuring that the nation would not grow dependent on

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[72] Wang Zheng. *Never forget national humiliation: historical memory in Chinese politics and foreign relations* (Columbia University Press, 2012): pp. 40–67.

[73] Alison Adcock Kaufman. The "Century of Humiliation," Then and Now: Chinese Perceptions of the International Order. *Pacific Focus.* 25:1 (2010); William A. Callahan. National Insecurities: Humiliation, Salvation, and Chinese Nationalism. *Alternatives*. 29 (2004): pp. 199–218.

[74] Wang, Zuoye. Saving China Through Science: The Science Society of China, Scientific Nationalism, and Civil Society in Republican China. *Osiris.* 17 (2002). See also Joseph Needham's extensive work on *Science and Civilization in China*.

[75] Wang. Saving China Through Science…; Victor Seow. A Tradition of Invention: The Paradox of Glorifying Past Technological Breakthroughs. *East Asian Science, Technology, and Society: An International Journal.* 16:3 (2022).

[76] As quoted in Jin, Canrong. "The Uncertainty of the International Situation and the Fourth Industrial Revolution" [世界形势的不确定性和第四次工业革命]. *Asia Pacific Security and Maritime Affairs* (2019). Translated by Fang Tianyu, *The Center for Strategic Translation.*

[77] Sigrid Schmalzer. "Self-Reliant Science: The Impact of the Cold War on Science in Socialist China." In Naomi Preskes & John Krige (eds.) *Science and Technology in the Global Cold War* (MIT Press Scholarship, 2014); Susan Greenhalgh. *Just One Child: Science and Policy in Deng's China.* (University of California, 2008): p. 55.

foreign powers. The central S&T policy aim at the time was to establish a basic national engineering competence and "catch up from behind."[78] The starting point was to introduce technologies from the Soviet Union, but weapons development proved an uphill struggle, given the PRC's scarcity of both resources and expertise, especially after Beijing-Moscow relations collapsed in 1960.[79] Moreover, Mao's revolutionary policymaking and distrust of intellectuals during the Great Leap Forward (1958–1962) and the Cultural Revolution (1966–1976) severely undermined S&T progress, to say nothing of the catastrophic consequences for food security and social welfare.[80] That China despite this managed to acquire nuclear weapons by 1964 is a considerable feat, made possible only by a total resource mobilisation driven by Mao's fear of military inferiority and political threats to Chinese socialism.[81]

When Deng Xiaoping (leadership period 1978–1989) assumed leadership, he too immediately embraced S&T as the key to strengthening China's national power. Deng believed that technological inferiority was a source of national weakness, not only in the past but also in the present.[82] First, Deng recognised that China would be able to achieve very little without the right S&T foundation. In 1977, the CCP adopted the "Four Modernisations" campaign that established the modernisation of science, industry, agriculture, and defence as key priorities:

> "without modern science and technology, it is impossible to build modern agriculture, modern industry or modern national defence. Without the rapid development of science and technology, there can be no rapid development of the economy."[83]

These priorities also resounded in the "reform and opening up" policy line, which in tandem with economic reforms introduced measures targeted at improving the nation's manufacturing. The Cultural Revolution left the industrial base poorly prepared for keeping pace with the inflow of technologies that ensued when the economy opened up.[84] Deng initiated reform campaigns to, among other aims, educate scientists and acquire technologies at low cost by requiring foreign-owned

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78 Zuoye Wang. The Chinese developmental state during the Cold War: The making of the 1956 twelve-year science and technology plan. *History and Technology.* 31:3 (2015).

79 Covell F. Meyskens, *Mao's Third Front: The Militarization of Cold War China* (Naval Postgraduate School, 2020): p. 24.

80 Schmalzer. "Self-Reliant Science"; Lieberthal, Kenneth. *Governing China: From Revolution Through Reform*. 2nd ed. (W. W. Norton & Company, 2004): pp. 103–104.

81 Tai Ming Cheung. *Innovate to Dominate: The Rise of the Chinese Techno-Security State* (Cornell University Press, 2022): pp. 216-217; Richard P. Suttmeier, Chinese Science Policy At a Crossroads. *Issues in Science and Technology*. 36:2. (2020): p. 59.

82 Yoram Evron. *China's Military Procurement in the Reform Era: The Setting of New Directions* (Routledge, 2015): pp. 70–71.

83 Deng Xiaoping. Speech at the Opening Ceremony of the National Conference On Science (1978-03-18).

84 Qiao Weiguo & Fang Chen. "Research on the Policy System and Implementation of Technology Importation, Absorption, and Re-innovation" [引进消化吸收再创新的政策体系与实施问题研究]. *Science and Technology for Development* [科技促进发展] 11 (2010): 37-40.

companies to transfer technologies to local partners.[85] Additionally, policymakers began consulting experts to draft effective policies and to justify political decisions as scientifically sound (to protect the CCP's control).[86]

A second consideration was military modernisation. Deng believed that visibly upgrading the capabilities of the People's Liberation Army (PLA) was vital to deter adversaries from initiating new aggression on China. Even though the development of nuclear weapons strengthened the PLA's standing, its overall technological level was poor. Still, Deng understood that the PLA's main problems were its size and poor discipline, i.e. issues not solved by modern equipment.[87] Meanwhile, the PRC's geopolitical environment was at its most stable in decades, and Deng deemed that shifting the PLA to a peacetime posture was relatively risk-free and, starting in 1979, repurposed much of its resources for economic development.[88] Even so, the PLA remained a key political ally and to secure its support, Deng approved a handful of defence R&D and procurement programmes. While self-reliance remained the goal, Deng pragmatically stated, "one must learn from those who are more advanced before he can catch up with and surpass them."[89] The 1980s thus became a golden decade of Western technological and military cooperation with the PRC. The US and Europe significantly helped Chinese manufacturers to build up their S&T abilities through exports, licensing, and direct investments.[90] The combined efforts of technological learning and absorbing Western managerial best practices slowly but surely allowed new technology to circulate in the economy and China's industrial performance began to take off.[91]

4.2 From catching-up to innovation

Jiang Zemin (leadership period 1989–2002) continued to expand reforms of the S&T system throughout his tenure. Jiang believed that economic development was central to achieving national rejuvenation and that science and technology were the means of advancing towards this goal. Overall, Jiang was less interested in achieving specific technological advancements than in expanding the technological toolbox available to Chinese economic development more broadly.[92] In

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[85] Joel R. Campbell. Becoming a Techno-Industrial Power: Chinese Science and Technology Policy. *Issues in Technology Invention*. 23 (2013): p. 3.
[86] Greenhalgh. *Just One Child*, pp. 50-55 & 270–273; Lieberthal. *Governing China*, pp. 129–130.
[87] Evron. *China's Military Procurement in the Reform Era*, pp. 67–72 & 90.
[88] June Teufel Dreyer. Deng Xiaoping and Modernization Of the Chinese Military. *Armed Forces & Society*. 14:2 (1988): pp. 220-221; Evron. *China's Military Procurement in the Reform Era,* pp. 94–98.
[89] Evron. *China's Military Procurement in the Reform Era,* pp. 70–73, quote from p. 79.
[90] Richard P. Suttmeier. From Cold War science diplomacy to partnering in a networked world. *Journal of Science and Technology Policy in China*. 1:1 (2010): p. 24: Ka Po Ng. *Interpreting China's Military Power: Doctrine Makes Readiness* (Taylor & Francis, 2005): pp. 71–72.
[91] Suttmeier. Chinese Science Policy At a Crossroads, p. 60; Barry Naughton. *The Rise of China's Industrial Policy 1978 to 2020* (Ciudad Universitaria, 2021): p. 14.
[92] Naughton. *The Rise of China's Industrial Policy 1978 to 2020*, pp. 43–44.

1995, the government adopted the slogan "revitalise the nation through science and education" (*kejiao xingguo*), a clear nod to the 1900s, and stepped up funding for university education and research as well as introduced measures to encourage stronger market participation in R&D.[93] In the late 1990s, the national innovation system concept made its way into policymaking circles. Jiang reportedly took an immediate liking to the concept, and it likely provided inspiration for the creation of the Ministry of Science and Technology and other S&T coordination organs.[94]

Militarily, the United States' use of technologies in the Gulf War deeply impressed Chinese observers, who realised that the PLA must prepare for high-technology wars. To this end, Jiang called for "strengthening the army with science and technology" (*keji qiangbing*) and oversaw the adoption of a new military strategic guideline on "local wars under high-tech conditions" in 1993 that emphasised the integration of information technology.[95] The preconditions for doing so were not ideal, however. After the Tiananmen Square massacre in 1989, the US and several European states implemented export controls on defence and dual-use technologies.[96] As a result, the PLA's demand for domestically produced armaments surged, prompting reforms of the defence industry and an increase in reported espionage incidents.[97]

The Hu Jintao administration (2002–2012) built upon Jiang's approach and assigned considerable attention to innovation and knowledge-creation as the core of national power.[98] The shift away from catching-up was made possible by the elevated S&T skill of Chinese firms and universities following decades of government encouragement.[99] Several policy documents from this time place innovation at the centre of economic planning. Most significant among these is the National Medium- and Long-term Plan for S&T Development (MLP) 2006–2020.[100] The MLP was central in charting out the direction of S&T development, with its ambition to close in on world-leading technology powers by 2020.[101]

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[93] Campbell. Becoming a Techno-Industrial Power: Chinese Science and Technology Policy, p. 6; Cao, Cong, Richard P. Suttmeier & Denis Fred Simon. China's 15-year Science and Technology Plan. *Physics Today* (2006).

[94] Kjeld Erik Brødsgaard & Koen Rutten. "Scientific Development and Domestic Demand (2003–2011)." In Kjeld Erik Brødsgaard och Koen Rutten (eds.). *From Accelerated Accumulation to Socialist Market Economy in China*. (Brill, 2017): p. 137.

[95] Tai Ming Cheung, Thomas Mahnken, Deborah Seligsohn, Kevin Pollpeter, Eric Anderson & Fan Yang. *Planning for Innovation: Understanding China's Plans for Technological, Energy, Industrial, and Defense Development* (Institute on Global Conflict and Cooperation, 2016): p. 26.

[96] Po Ng. *Interpreting China's Military Power,* pp. 36, 109 & 129.

[97] Philip C. Saunders & Joshua K. Wiseman. *Buy, Build, or Steal: China's Quest for Advanced Military Aviation Technologies* (National Defense University Press, 2011): p. 41.

[98] Cheung. *Innovate to Dominate*, pp. 11–12.

[99] Yoram Evron & Richard A. Bitzinger. *The Fourth Industrial Revolution and Military-Civil Fusion* (Cambridge University Press, 2023): p. 42.

[100] Cao et al. China's 15-year Science and Technology Plan.

[101] Naughton. *The Rise of China's Industrial Policy 1978 to 2020*, pp. 50–51 & 65–66.

Table 3. MLP's four numerical targets and their fulfilment by 2020.[102]

Indicator	MLP Target (2006)	Fulfilment (2020)
National R&D expenditure as a percent of GDP	2.5 percent	2.4 percent
Dependence on foreign technology	30 percent	31.2 percent
Contribution of S&T progress to economic growth	60 percent	59.5 percent
Patent registrations and academic paper citations	Global top five	3rd place in patents 2nd place in citations

The MLP declared indigenous innovation (*zizhu chuangxin*) a strategic priority. The idea is to replace technology import dependencies with domestic alternatives and original advancements. The need for technology indigenisation was not a new idea, as the above review shows. Yet, the problems of relying on foreign technologies had grown as the PRC integrated into the world economy. China's entry into the World Trade Organization in 2001 enabled access to international markets, but also highlighted the limitations of its growth model: the export goods that drove the PRC's growth were produced using foreign technology or by foreign-invested firms, meaning that the profits went to foreign companies and patent owners, not to local producers.[103] This insight sparked intense internal debate on the future of China's economic strategy just as Hu came into office. The CCP under Hu concluded that Chinese manufacturing would lose global competitiveness without increased patenting and intellectual property rights ownership—in other words, invention.[104]

Indigenous innovation also reflects defence-related motives. At the time, external security concerns demanded an increasing share of the leadership's attention. The bombing of the PRC embassy in Belgrade in 1999 and the US's counterterrorism campaigns in the Middle East after 2001 reinforced the urgency of developing the PLA's strategic and asymmetric capabilities, not only to deter against invasion but also to support the state's expanding external interests.[105] Continued military modernisation was critical—but possible only with a growing economy and S&T skill base. Meanwhile, the reliance on copying foreign technologies created a vulnerability to fluctuations in the security landscape, of which the denied access to technologies post-1989 was proof. Observing this, the MLP concludes,

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[102] Yutao Sun & Cong Cao. Planning for science: China's "grand experiment" and global implications. *Humanities & Social Sciences Communications.* 8 (2021): p. 3.

[103] Richard P. Suttmeier, Xiangkui Yao & Alex Zixiang Tan. Standards of Power? Technology, Institutions, and Politics in the Development of China's National Standards Strategy. *Geopolitics, History, and International Relations* 1:1 (2009): p. 54; Cao et al. China's 15-year Science, p. 39.

[104] Brødsgaard & Rutten. "Scientific Development," pp. 135–137; Tim Rühlig. *Technical standardisation, China and the future international order: A European perspective* (Heinrich Böll Stiftung, 2020): pp. 8–10.

[105] Cheung. *Innovate to Dominate*, pp. 10–11; Cheung et al. *Planning for Innovation*, p. 22.

> "in areas critical to the national economy and security, core technologies cannot be purchased. If our country wants to take the initiative in the fierce international competition, it has to enhance its indigenous innovation capability."[106]

To encourage original achievements and insulate the S&T base from external pressures, the leadership saw a need to build technological competencies in sectors that benefit both civilian and defence needs. This led to the establishment of 20 large-scale engineering and science programmes, known as the Megaprojects, in which efforts were concentrated under top-down central guidance and state funding.[107] In a similar vein, the state invested massive sums in seven "strategic emerging industries" a few years later to thrust the PRC out of the global financial crisis and to establish Chinese manufacturing in emerging segments while global competitors were distracted.[108] Still, the distinguishing feature of the MLP was that, for the first time, it presented a blueprint for *how* China should evolve from importing to producing knowledge: the so-called IDAR (Introduction—Digestion—Absorption—Re-innovation) strategy. The first step is to *introduce* foreign technology by filling high-priority knowledge gaps through international academic exchanges, targeted outward foreign direct investment, and talent recruitment. Second, researchers must *digest* the know-how, i.e. familiarise themselves with potential applications. Third, the technology must be *absorbed* and assimilated with local knowledge. Ideally, manufacturers would then become capable of *re-innovation*: not only reproducing foreign-derived technology but also altering it to meet Chinese needs.[109] However, in practice, and despite the government's best efforts, it has been argued that China's high-tech industries have emerged mostly through trial and error by local authorities and enterprises, rather than through central policy.[110]

4.3 The historical convergence

The CCP has long held the firm belief that the PRC has a rightful historical claim to global power status, and that technological backwardness was a central weakness that led to the ousting from the world elite. As such, the restoration of national power requires a world-leading technological foundation. Under Xi Jinping's (2012–present) leadership, these ideas have not changed. If anything, they have grown stronger. Political discourses highlight more than ever innovation as a source of national strength and present S&T as the universal solution to all sorts of problems and challenges to the restoration of China's lost status that

[106] PRC State Council. *The National Medium- and Long-Term Program for Science and Technology Development (2006–2020)*.
[107] Cheung. *Innovate to Dominate*, p. 207; Cheung et al. *Planning for Innovation*, pp. 32–33 & 119.
[108] Naughton. *The Rise of China's Industrial Policy 1978 to 2020*, pp. 49 & 60–65.
[109] Cheung. Innovation in China's Defense Technology Base, p. 737.
[110] Dan Breznitz & Michael Murphree. *The Run of the Red Queen* (Yale University Press, 2012): p. 19.

traditional approaches have failed to solve.[111] Xi has made national rejuvenation the ideological core of his leadership. Xi understands the great rejuvenation as closer at hand today than at any other time since the Opium War—meaning that closing the remaining gap is an urgent task. This "final mile" mentality is particularly visible in Xi's signature initiative from his first years in office, the "China Dream," and the emphasis placed on S&T in achieving social, economic, and military modernisation by 2049.[112] Xi's view of innovation largely recycles well-known themes: technological self-reliance, growth and economic power, military force upgrading, and international status elevation.

Table 4. An overview of the national power goals underpinning the pursuit of innovation under Xi Jinping.

Economic power goals	• Fostering innovation to drive economic growth through advanced manufacturing and industrial upgrading • Sustaining internal legitimacy
Security and military power goals	• Boosting S&T self-reliance and reducing China's dependence on foreign technology imports to build a resilient economy able to withstand external shocks • Military modernisation on a world-class level, pursuit of disruptive technologies
Political power goals	• Becoming a global tech power with strong influence over the development of emerging core technologies • Display institutional advantages of the CCP regime

First, the quest for innovation in science and technology is driven by the CCP's desire for economic power. Chinese political thought understands manufacturing as the "foundation of world power" and technological revolutions as a platform for catapulting the leaders in next-generation technologies into great powers.[113] The United States' power status is accredited to its leadership in the second industrial revolution.[114] The matter of China's innovative manufacturing capability is considered particularly urgent because the party perceives the world as on the cusp of the Fourth Industrial Revolution (4IR), centred on emerging technologies such as artificial intelligence (AI) and quantum computing, where China *must* position itself as a competitive contestant. Central party rhetoric dramatically declares the

[111] Wang Xiaoguang. The "Techno-Turn" of China's Official Discourse on Nationalism. *Communist and Post-Communist Studies*. 54:4 (2020); Susan Greenhalgh. "Governing Through Science: The Anthropology of Science and Technology in Contemporary China." In Susan Greenhalgh & Li Zhang (eds.) *Can Science and Technology Save China?* (Cornell University Press, 2020): p. 3.

[112] Xinhua. "Full text of Xi Jinping's report at 19th CPC National Congress" (2017-11-03); Cheung. *Innovate to Dominate*, pp. 16-17; Xi Jinping. "Striving to become the world's centre and innovation hub" [努力成为世界主要科学中心和创新高地]. *Qiushi* (2021-03-15).

[113] PRC State Council. *Notice of the State Council on the Publication of "Made in China 2025"* (CSET Translation, 2022).

[114] Ling Chen & Barry Naughton. An institutionalized policy-making mechanism: China's return to techno-industrial policy. *Research Policy*. 45. (2016); China Institutes of Contemporary Relations. "General Laws of the Rise of Great Powers" [大国崛起的一般规律]. (2021-04-15).

stakes at hand as a matter of existential survival: "without a strong manufacturing industry, there will be no country and no nation."[115] A recent state media commentary similarly declares, "the failure to catch the latest techno-scientific wave means stagnation, decline, and defeat."[116] The CCP describes the coincidence of the unfolding technological revolution with China's better-than-ever economic and technical capabilities as a "strategic opening unmatched in history" to claim its rightful leadership in the international system.[117] A recent policy statement by Foreign Minister Wang Yi describes the imperative to act:

> "Currently, changes of the world, of our times and of historical significance are unfolding like never before. Transformation not seen in a century is accelerating across the world. A new round of technological revolution and industrial transformation is well under way. A significant shift is taking place in the international balance of power. . . We are now better positioned to seize the historical initiative and shape the trajectory of the world."[118]

In addition to seeking international economic power, innovation is essential to economic growth. When Xi assumed office in 2012, the economy had entered a period of contracted growth. This persists today as the "new normal" and challenges the regime's ability to deliver welfare to its citizens.[119] To reverse this trend, the "new development philosophy" of 2015 and its centrepiece concepts, the "new quality productive forces" and "high-quality economic development," draw heavily upon Marxist terminology and, unsurprisingly, place a premium on innovation to move Chinese manufacturing up the value chain, focusing on the creation of intellectual property rights.[120] By integrating smart technologies in traditional industries, the CCP hopes to produce high-quality goods that build a positive brand image for PRC-made products, internationally and domestically, and to transform unproductive sectors into new drivers of growth.[121]

Not only does a slowing economy reduce the amount of funds available for government S&T spending (such as R&D subsidies), continued growth is needed to prevent performance-based challenges to the CCP's political legitimacy. The stated aim of the philosophy is to enhance people's quality of life and environmental practices, reflecting popular pressures on the CCP to keep delivering improved living standards in a sustainable fashion.[122] To the extent that economic

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[115] *Notice of the State Council on the Publication of "Made in China 2025."*

[116] China Institutes of Contemporary Relations. "General Laws of the Rise of Great Powers."

[117] Cheung. *Innovate to Dominate*, pp. 56–61; Jin. "The Uncertainty of the International Situation and the Fourth Industrial Revolution."

[118] Wang Yi. Foster a Favorable External Environment For Further Deepening Reform Comprehensively To Advance Chinese Modernization. *Ministry of Foreign Affairs of the PRC.* (2024-08-13).

[119] Zongyuan Zoe Liu. China's Real Economic Crisis. *Foreign Affairs* (2024-08-06).

[120] PRC State Council. China unleashes new quality productive forces in push for reform, innovation (2024-06-25).

[121] Arthur R. Kroeber. Unleashing "new quality productive forces": China's strategy for technology-led growth. *Brookings* (2024-06-04).

[122] Keith Bradsher & Chris Buckley. China Shows Few Signs of Tilting Economy Toward Consumers in New Plan. *The New York Times* (21/7 2024).

development is a condition for the CCP's political survival and the continuation of the PRC regime as we know it today (recall the belief that without a strong industry, there will be no country and no nation), the application of innovation to stimulate sustainable growth may be perceived as the leadership's core strategic priority.

Through the lens of national power, a lagging innovation capacity also poses significant national security concerns. Under Xi, party discourse has shifted from "development first" to emphasising development and security as equally important and mutually reinforcing: "national security is the prerequisite for development and development is the guarantee of security."[123] Concurrent with, and perhaps driving this shift, there has been a merging of security domains in top-level political thought. The Comprehensive National Security Concept adopted in 2014 embeds external and internal political, economic, and military security in a single perspective.[124] This integration has deepened over the past decade, in step with the outwards expansion of the CCP's political interests, combined with an increasingly grave perception of external threats, such as the cooling of US-China relations and the stronger push for containment and "de-risking" in Washington and Brussels. As pressures on China have intensified (and, Beijing believes, will continue to do so), the need to insulate the economy and increase control over its supply chains through increasing self-reliance becomes an immediate concern.[125] This sense of being "under siege" leads the CCP to prepare for "long-term enmity" with the United States; industrial initiatives that originally targeted filling gaps in global supply chains have been re-oriented towards filling domestic gaps, especially in defence-related sectors.[126]

Alongside the globalisation of Chinese interests and the greater prioritisation of security objectives, military competition and power projection have become more pronounced parts of the CCP's strategic thinking on how to achieve and protect its national interests at home and overseas.[127] 4IR technologies such as AI will create a military advantage and, consequently, greater geostrategic leverage for the nations that master them.[128] Where PLA planners previously differentiated between peacetime and wartime capabilities, there is today stronger support for using military force at different levels of intensity to advance the PLA's peacetime

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[123] Howard Wang. "Security Is a Prerequisite for Development": Consensus-Building toward a New Top Priority in the Chinese Communist Party. *Journal of Contemporary China*. 32:142 (2022): pp. 525–539. Quote by Xi from Cheung. *Innovate to Dominate*, p. 302.

[124] Jianfei Liu. "An Evaluation of China's Total National Security Environment" [以总体国家安全观评估中国外部安全环境]. *International Studies* [国际问题研究]. (2014-10-14).

[125] Tai Ming Cheung, Barry Naughton & Eric Hagt. *China's Roadmap to Becoming a Science, Technology, and Innovation Great Power in the 2020s and Beyond* (IGCC, 2022): p. 9.

[126] Cheung, Naughton & Hagt. *China's Roadmap*, p. 11; Yu Jie. *China "under siege": How the US's hardening China policy is seen in Beijing* (Chatham House, 2024).

[127] Howard Wang, Gregory Graff & Alexis Dale-Huang. *China's Growing Risk Tolerance in Space: People's Liberation Army Perspectives and Escalation Dynamics* (RAND, 2024): pp. 13–18.

[128] C.f. Evron & Bitzinger. *The Fourth Industrial Revolution and Military-Civil Fusion*, pp. 2 & 17.

missions as "meets the needs of the security situation."[129] To keep pace with the United States in defence innovation, the PLA views intelligent warfare as critical: "facing disruptive technology, [we] must. . . seize the opportunity to change paradigms. Whoever doesn't disrupt will be disrupted!"[130] Insufficient innovation thus becomes a significant concern for national security and the PRC's aspirations to military superiority: Xi Jinping has called for the PLA to reach significant modernisation progress by 2027 and become a "world-class" military by 2049.

Third, S&T innovation is an integral element of China's global outreach strategy and pursuit of overseas economic and political interests. Scholars have suggested that pioneering new technologies in a few industrial sectors will not be sufficient to secure China's claim to economic power, as innovation-driven growth needs to diffuse widely throughout the economy to generate substantial productivity-raising effect.[131] Even so, there are benefits to be reaped from simply being the first: gaining the chance to set the standard. Technical standards are agreed-upon instructions on how to manufacture and operate a given item, providing a baseline that steers the continued development. The standard-setter therefore wields strong influence in the early stages of the innovation process to shape global norms and governance frameworks in their economic, political, and strategic favour.[132] Standard-setting is also economically lucrative, bringing in royalty fees to the patent holder.

The Chinese government has called for improving the nation's ability to define international technical standards as a "global standards-setting power" and the Innovation-Driven Development Strategy (see Section 5.1.2 below) explicitly aims to create a technological dependence on China among international competitors by creating patent-worthy technology at the innovation forefront.[133] PRC officials are lobbying for incorporating Chinese technologies in new international standards, albeit with limited success. PRC-made technologies and designs exported on the global market, primarily through the Belt and Road Initiative, therefore offer another avenue for internationalising Chinese standards.[134]

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[129] China Military. "What is the purpose of the use of military force in peacetime?" [和平时期军事力量运用，目的在哪里？] (2016-11-17).

[130] Elsa B. Kania. *Battlefield Singularity: Artificial Intelligence, Military Revolution, and China's Future Military Power* (Center for a New American Security, 2017): p. 13.

[131] Rebecca Arcesati, Katja Drinhausen & Max J. Zenglein. Having it both ways—Third Plenum promises reforms and doubles down on Xi's grand vision. *MERICS* (2/8 2024); Jeffrey Ding. *Technology and the Rise of Great Powers.* 1st (Princeton University Press, 2024).

[132] Björn Fägersten & Tim Rühlig. *China's Standard Power and its Geopolitical Implications for Europe* (The Swedish Institute of International Affairs [UI], 2019): p. 14; Tim Rühlig. China's Technological Power—Implications and Risks. *Diálogo Político*. 1 (2023): p. 92.

[133] *Outline of the National Innovation-Driven Development Strategy;* Dieter Ernst. *Indigenous Innovation and Globalization: The Challenge for China's Standardization Strategy*. (East-West Center, 2011): p. 103; Antoine Bondaz. *Promoting "soft connectivity": China's standards-setting reforms and international ambitions* (Fondation pour la Recherche Stratégique, 2021): pp. 3–4.

[134] Fägersten & Rühlig. *China's Standard Power*, pp. 13–14; Rühlig. *Technical standardisation*, pp. 21–26; Bondaz. *China's standards-setting reforms*, p. 13.

Internationally non-harmonised standards can create lock-in effects where the recipient countries become dependent on companies that adhere to Chinese standards (i.e., PRC firms) for maintenance and redevelopment. Such dependencies may function as an instrument of foreign policy and contribute to the growth of Beijing's geopolitical and economic power, and may create pathways to political dependency.[135]

Finally, the Chinese government views the contention for technological leadership and global power as systemic, as a confrontation of political systems. The idea of China's rejuvenation is not only to catch up with the West materially, but also to reinstate the superiority of Chinese political, social, cultural, and philosophical practices.[136] As some Chinese scholars write,

> "behind the curtain lies a confrontation of ideas and concepts in modern national governance, the competition of institutions and systems, and the competition to see whose system is more adaptable. . . and the strength of society as a whole to support national security and development."[137]

The heavy influence of Marxist ideas about production relations in recent economic policy-making and the concept of "new quality productive forces" has been interpreted as signifying China's ambition to demonstrate the superiority of Chinese socialism over capitalism.[138] Innovation achievements can play a propaganda role as examples of the institutional advantages of the Chinese political and innovation systems. The innovation system is described as a "whole-of-nation" system, able to "twist the strengths of the government, the market, and the society into a single rope."[139] In particular, official discourses tout China's capacity for mobilising resources as a major advantage of the socialist system. According to Xi Jinping, the country's "whole-of-nation" approach to innovation gives the PRC an exceptional ability to "concentrate our efforts on doing big things" (*jizhong liliang ban da shi*), implying that, in comparison, democratic governments do trivial things.[140] State media rhetoric tends to give more credit for innovative performance to the advantages of the system than to the technological skill of the individual innovator.[141]

In sum, Beijing's innovation imperative in the Xi era has three central objectives: first, to shift to high-quality economic growth to avoid economic stagnation and

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[135] Rühlig. *Technical standardisation*, p. 10.
[136] Callahan. National Insecurities.
[137] Jiang Luming, Wang Weihai, Liu Zuchen. Initial Discussion on the Military-Civil Fusion Strategy [军民融合发展战略探论]. (People's Press, 2017) as cited and translated in Stone & Wood. *China's Military-Civil Fusion Strategy,* p. 36.
[138] Eun Jong-hak. The U.S.-China divergence: Korea's Schumpeterian Solution. *Korea JoongAng Daily* (2025-03-06).
[139] People's Daily. "Give full play to the advantages of the new national system" [充分发挥新型举国体制优势] (2024-06-27).
[140] *Outline of the National Innovation-Driven Development Strategy*; Wang. The "Techno-Turn," p. 225.
[141] Wang. The "Techno-Turn," p. 226.

expand the PRC's global economic power. Second, to enhance technological self-reliance and boost China's economic resilience as well as to incorporate new and disruptive technologies in the PLA's capabilities. Third, to support China's pursuit of global influence, becoming a technological first-mover and displaying the institutional advantages of the Chinese system. Individually, none of these are unique to Xi. However, the increased focus on security and the integration of goals into a grand strategic framework for comprehensive national power are more prominent than previously.

4.4 Innovation with Chinese characteristics

As is shown above, Chinese political discourse frames innovation capacity as a key resource in the confrontation of political systems. We conclude this chapter by briefly examining the characteristics of Chinese innovation, returning to the conundrum raised in the introduction regarding China's potential to improve its innovation capacity. What systemic features may have enabled the PRC's shift from "copycat" to "emerging S&T powerhouse"?

First, similarly to Europe and the US, the Chinese public has an incredibly positive view of science and technology. According to the World Values Survey, 9 in 10 Chinese residents believe S&T improves life standards and makes the world a better place. This places China at the top of the surveyed countries.[142] This attitude is rooted in S&T's symbolism of prosperity, modernity, and power in the historical narratives from the 20th century (see Section 4.1), connotations that grew stronger during the economic reform era. This association with wealth predisposes the public to embrace new technological innovations with great enthusiasm, a characteristic clearly visible in the widespread adoption of mobile payment and e-commerce services.[143] This suggests that, on a population level, the PRC enjoys favourable conditions for incubating, implementing, and diffusing innovations. The Chinese government's claim that it enjoys an institutional advantage in the "strength of society as a whole to support national security and development" is therefore not unfounded.[144]

Second, everything about Chinese science is big: big ambitions, big funding, and a big skill and consumer base. The pursuit of "big science" and Xi Jinping's "big things" can be traced to the connection made in Chinese political imaginaries between big scientific achievements (nuclear weapons, space technologies, mega-engineering etc.) and national power. Big goals naturally require big funding: China is the world's second biggest R&D spender (26 percent of the global total

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[142] R. Inglehart., C. Haerpfer, A. Moreno, C. Welzel, K. Kizilova, J. Diez-Medrano, M. Lagos, P. Norris, E. Ponarin & B. Puranen et al. (eds.). *World Values Survey Wave 7* (JD Systems Institute, 2022).

[143] Alicia García-Herraro & Robin Schindowski. *China's Quest for Innovation: Progress and Bottlenecks* (Bruegel, June 2023): pp. 7–8.

[144] Jiang, Wang, & Liu as cited in Stone & Wood. *China's Military-Civil Fusion Strategy,* p. 36.

in 2023), allocating more funding to S&T than many governments around the world spend *in total*.[145] Moreover, China has a big population: 1.4 billion people.[146] One implication of this, in combination with the large funding, long manufacturing experience, and consistent efforts to educate elite scientists and engineers, is that China can afford to industrialise the innovation process and assign greater numbers of generally highly competent staff to work on projects.[147] While quantity does not have to mean quality, *statistically,* more brains dedicated to solving a problem is bound to produce at least some brilliant outcomes.[148] Additionally, the big population translates into an equally big and diverse internal market. On the one hand, this allows for more consumer feedback and other benefits of scale. For example, in terms of digital services, the large user base allows firms to collect more data, which can be used for refining the product or service.[149] On the other hand, introducing an innovation that satisfies so far unmet demands on the market unlocks huge business potential. Business interests to fill gaps in the market provide strong incentives for innovative output, known as demand-pull innovation.[150] In this sense, China's "big science" benefits invention.

Third, Chinese innovation is competitive. The CCP understands that Chinese manufacturing eventually will lose competitiveness on the global market without bringing something new to the table, i.e. invention.[151] Domestically, private companies have been critical drivers of innovation in China since the economy opened up in the 1980s. While state-owned enterprises (SOEs) are important actors in the economic and innovation arenas, they are generally under less pressure to generate profit than private firms are. Private firms have poorer access to secure sources of funding, including credit markets and government subsidies, and must thus compete for market shares to stay in business—and the competition is fierce.[152] Informal political connections between businesses and government officials are conditional for firms to secure financial R&D support.[153] This is not to say that publicly funded actors do not innovate, or that private businesses do not receive government support. Still, private sector actors carry a heavy responsibility

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[145] Bonaglia, Rivera León & Wunsch-Vincent. End of Year Edition—Against All Odds; World Population Review. *Government Budget by Country 2024*.
[146] CIA World Factbook. *China: People and Society* (2024-04-09).
[147] Williamson. Chinese Cost Innovation, p. 550.
[148] Tim Rühlig. *The Sources of China's Innovativeness* (DGAP Analysis no. 5, German Council on Foreign Relations, 2023): p. 7.
[149] C.f. Niklas Wadströmer, David Gustafsson & Frida Lampinen. China's Push in Artificial Intelligence: Covert Dangers of Using the Digital Silk Road to China, in Christopher Weidacher Hsiung, Cecilia During, Oscar Almén, Peter Stenumgaard & Annica Waleij (eds). *Strategic Outlook 10: China as a Global Power* (FOI, June 2024): pp. 124–125.
[150] Michael Peters. The impact of technology-push and demand-pull policies on technical change—Does the locus of policies matter? *Research Policy*. 41:8 (2012): pp. 1296–1308.
[151] Brødsgaard & Rutten. "Scientific Development and Domestic Demand (2003-2011)," pp. 135–137.
[152] Zheng Song, Kjetil Storesletten & Fabrizio Zilibotti. Growing Like China. *American Economic Review*. 101:1 (2011): pp. 202–204; Rühlig. *The Sources of China's Innovativeness,* p. 7.
[153] García-Herraro & Schindowski. *China's Quest for Innovation,* pp. 15–17.

in conducting R&D, experimenting with new methods and business models, commercialising, and identifying and exploiting emerging markets.

In particular, the rate at which companies cycle through design, batch production, and market launch can be as short as a few days while still retaining reasonable quality. Unlike Western enterprises, which tend to outsource much of their production overseas, Chinese tech firms generally operate in much closer proximity to their production lines and thus enjoy a much shorter lead-time for prototype or product deliveries.[154] This allows companies to swiftly adjust or improve their products or processes in line with consumer feedback and changing market preferences. Short launch-test-improve cycles are practiced systematically at several major tech firms, such as Tencent, Huawei, and Lenovo.[155] This approach should benefit invention as well as incubation, in the sense that repeated testing demonstrates which ideas work (gaining them status and influence), and which do not.

[154] Peter J. Williamson. Chinese Cost Innovation, the Shanzhai Phenomenon, and Accelerated Innovation in *The Oxford Handbook of China Innovation*, pp. 544–545.
[155] Williamson. Chinese Cost Innovation, pp. 545–548.

5 S&T policymaking under Xi Jinping: A process-model perspective

The Chinese party-state has clear strategic incentives to promote innovation in science and technology. Moreover, Xi Jinping believes China is better positioned today than ever before to become a technological leader and maximise the economic, security, and influence benefits attainable through innovation. This chapter builds upon the analytical framework developed in chapter 3 to examine the question "*What measures of Chinese S&T policies under Xi Jinping stimulate what phase(s) of the innovation process?*" Are certain phases over- or under-represented in national policy, as Chapter 3 describes? The aim of this analysis is to test whether a processual approach is useful to interpret and understand China's S&T innovation governance, and in so doing, identify some key implications that establish a point of departure for future studies that may holistically assess the strengths and weaknesses of China's innovation efforts. The analysis indicates that PRC innovation policies focus on stimulating invention. Even though the innovation system exhibits characteristics that benefit incubation, implementation and diffusion, national-level policies do not make any particular use of these strengths. Instead, these tasks are left to develop organically through economic dynamics on the domestic civilian and defence markets.

In the making of this report, the authors have not identified evidence suggesting that S&T innovation planning in the PRC is conducted systematically based on models of innovation or innovation processes. However, it is well-documented that Chinese experts have been contributing to the drafting process of policies on both national and local levels since the late 1970s.[156] To raise two examples, more than 2000 experts provided input to the drafting of the MLP, and the 13th Five-Year Plan was advised by a 55-member committee of experts explicitly selected for their competence in making suggestions for innovation-driven development.[157]

It is beyond the scope of this report to evaluate the influence of consulted scholars on government policies. Still, it is notable that innovation process models have an established presence within Chinese scholarly circles, meaning it is theoretically possible that this way of thinking is guiding national policy initiatives to some

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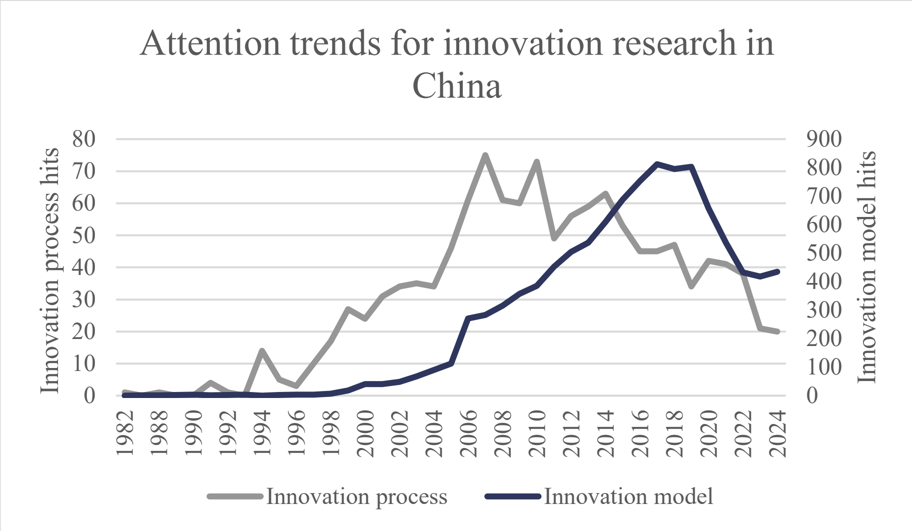
[156] See, for example, Jost Wübbeke. China's Climate Change Expert Community-principles, mechanisms and influence. *Journal of Contemporary China*. 22:82 (2013): pp. 712–731; Yongdong Shen, Meng U. Ieong & Zhihang Zhu. The function of expert involvement in China's local policy making. *Politics & Policy*. 50:1 (2022): pp. 59–76.

[157] Cao et al. China's 15-year Science and Technology Plan; "Demystifying the core think tank of the 13th Five-Year Plan: 4 entrepreneurs selected" [解密 '十三五'规划核心智囊：4 名企业家入选]. *Financial State Weekly* [财经国家周刊] (2015-07-10).

extent. After all, the introduction of the national innovation systems concept likely influenced Jiang Zemin's S&T policymaking in the 1990s (see Section 4.3). According to data available in the PRC scholarly database CNKI (China National Knowledge Infrastructure), the key word "innovation process," *chuangxin guocheng*, has garnered attention in Chinese academic research since the mid-1990s, developing markedly around 2004–6, about the time of the drafting and adoption of the MLP. Similarly, the keyword "innovation model," *chuangxin moshi,* has drawn significant attention since the mid-2000s, gaining traction gradually through the 2010s and culminating in the years after the launch of the IDDS in 2016 (see Figure 1 below).[158]

Figure 1. A graph illustrating the attention trends for innovation keywords in the CNKI database.



The apparent tendency of trends to grow in parallel with major policy launches may suggest that the policy-drafting process is influenced by, or itself influences, emerging research, though a deeper analysis would be necessary to substantiate this claim. Further, some of the most cited articles tagged with "innovation process" in CNKI focus on industry and academia research cooperation, innovation in small and medium-sized enterprises, and the establishment of industrial innovation clusters. These aspects are also focal points of some recent government policy initiatives, suggesting this or adjacent research has had some significance in the policymaking process.

[158] CNKI Attention Index Analysis results generated on 2025-02-12. Hits include journals, dissertations, newspapers, and conference papers. "Innovation process model" is not a registered keyword.

In any case, looking into the question of "What measures of the respective policies stimulate what phase(s) of the innovation process?" presents an interesting analytical exercise. The analysis applies a similar analytical framework as the one used in Chapter 3. It looks as follows.

Policy plan	Policy measure			
	Invention	Incubation	Implementation	Diffusion

5.1 S&T policies under Xi

"Policy plan" in the left-most column in the analytical framework above refers to the Chinese S&T policy that is analysed. Xi Jinping has invested significant effort and political capital in S&T policymaking since assuming office in 2012. As such, there is plenty of material to analyse. For purposes of practicality and policy relevance, this analysis is limited to the most significant and defence-relevant plans: Made In China 2025, the Innovation-Driven Development Strategy, the Artificial Intelligence Development Plan, and the 14th Economic Five-Year Plan.

Before introducing these plans, it is necessary to put them into context. S&T plans in the Chinese political system play an important role as tools of political signalling.[159] The PRC political-economic system is characterised by a complex bureaucracy with competing lines of authority, both geographically and state-vs-party. In essence, public officials have several bosses in different places, which presents significant challenges in establishing the order of priority and identifying the organisation that has final authority in a specific issue. Lieberthal refers to this phenomenon as "fragmented authoritarianism."[160] Breznitz and Murphree find that the political system is characterised by "structured uncertainty," defined as an "institutional condition that cements multiplicity of action without legitimising any specific course or form of behaviour as the proper one."[161]

In other words, the PRC is far from a unitary actor. Different actors and levels of government pursue uncoordinated and at times inconsistent policy actions. Decentralized economic decision-making, in particular, has led many economic actors to prioritise local development interests above national directives. Breznitz and Murphree argued in 2012 that Chinese policy reforms typically lack defined goals and means, creating an ambiguous and uncertain policy environment. The fear of interpreting the centre's intentions incorrectly is particularly prevalent among economic actors concerning S&T and innovation since these domains are intimately intertwined with China's self-image and understanding of its place in the international system.[162] An insecure actor may prefer doing nothing to doing

[159] Rühlig. *The Sources of China's Innovativeness,* p. 6.
[160] Lieberthal. *Governing China*, p. 187.
[161] Breznitz & Murphree. *The Run of the Red Queen*, pp. 38–42. Definition from p. 12.
[162] Ibid, p. 48.

wrong. Moreover, the rotation of local officials every five years is a systemic disincentive to mobilising long-term engagement.[163]

In this context, it is possible to interpret Xi Jinping's active and high-profile S&T policymaking as an attempt to bring more clarity to the innovation arena by clearly communicating the political centre's expectations in a way that leaves some leeway for specific implementation choices but where the fundamental intent can hardly be misinterpreted. Otherwise put, the policies serve a communicative function, more so than an instrument to control the decisions of innovation actors. Indeed, Xi early on recognised the challenges posed by policy ambiguity stemming from China's too many overlapping initiatives, each with too many actors involved, which had piled up after decades of continuous policymaking in the S&T domain.[164] When authorities reviewed the MLP's progress in 2012, they found it fell far short of expectations and that the increased funding had contributed to concealing many weaknesses in the S&T system.[165] Before enacting new policies of his own, Xi thus initiated a merger in 2014 of hundreds of existing S&T plans into five comprehensive programmes under unified management.[166]

While Xi's policymaking content and style in many ways carry on the legacy of previous plans, his approach is new in the sense that it seeks to satisfy both development and security needs, and to the extent possible, promote progress towards these goals in the *civilian and defence* ecosystems *simultaneously*. The military-civil fusion (*junmin ronghe*) strategy, adopted as a national strategy in 2015, provides critical context for interpreting China's S&T plans. Military-civil fusion (MCF) refers to the creation of synergies and military-civil sharing of information, resources, and capabilities to support China's transformation into a powerful nation.[167] Technology development is costly and knowledge remains a limited resource, even though the base of expertise is expanding. MCF seeks to escape the trade-off between "guns and butter," i.e. achieving one goal (economic development or defence construction) at the expense of the other by establishing a cohesive dual-use system with a common technology pool.[168]

The fundamental premise of MCF is far from new. All PRC leaders have sought to integrate military and civil competencies in various ways, primarily so that the national economy benefits from defence resources.[169] However, Xi's MCF strategy *significantly* elevates the importance of cross-domain resource-sharing, particularly to benefit the PLA's modernisation. Some scholars view MCF as a

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[163] García-Herraro & Schindowski. *China's Quest for Innovation,* pp. 15–17.
[164] Zhijian Hu, Zhe Li & Xianlan Lin."Reforms of the science and technology management system." In Xiaolan Fu (ed.) *The Oxford Handbook of China Innovation*. (Oxford University Press, 2021): p. 242.
[165] Cheung et al. *Planning for Innovation*, p. 34.
[166] Hu et al. "Reforms of the science and technology management system," p. 242.
[167] Stone & Wood. *China's Military-Civil Fusion Strategy,* p. 8; Cheung. *Innovate to Dominate*, p. 87.
[168] Evron & Bitzinger. *The Fourth Industrial Revolution and Military-Civil Fusion*, p. 4; Stone & Wood. *China's Military-Civil Fusion Strategy*, pp. 26 & 58-9. Cheung. *Innovate to Dominate*, p. 12.
[169] Evron & Bitzinger, pp. 102–104.

strategic frame within which to weave other initiatives.[170] MCF also shapes legislation: the National Defence Law, revised in 2022, for example, now emphasises national coordination to mobilise state-owned and private enterprises for the research, development, and production of weapons, as well as strengthens the military leadership's mandate to mobilise military *and civilian* assets to defend national interests in China and abroad.[171] Indeed, since 2022, the political centre reportedly prefers the term "national strategic integration," partly to highlight the integrative aspect and partly to avoid the scrutiny that MCF has attracted from foreign observers.[172] Although military-civil interconnectivity has improved in the past decade, integration is incomplete. A strong institutional latency and unwillingness to "be fused" have proven difficult to overcome. The impact of civilian resources on advancing the PLA's armament remains limited, if difficult to assess.[173]

On a final note, it should be clarified which policies this analysis *does not* examine. First, the analysis is limited to national-level policies and does not consider regional or local-level initiatives. Local priorities can diverge quite a bit from national-level prescriptions, but lower-level policies carry less authority as political signals. Second, several high-level policies are kept away from the public eye. The new Medium- and Long-term Plan for S&T Development (MLP 2021–2035), for example, remains unpublicised. This secrecy could indicate that the government believes foreign competitors may seek to prevent, disrupt, or otherwise frustrate China's plans if publicised. China is also increasingly, if selectively, limiting its exports of technology, arguably a measure to obscure its S&T progress to external observers and safeguard its interests in innovation.[174]

5.1.1 Made In China 2025

Xi's first major S&T initiative was the Made in China 2025 (MIC25) plan. Launched in 2015, MIC25 aims to establish innovation as the core of national manufacturing by 2025, so that China may become a world-leading manufacturing superpower by 2049. The plan explains that the Chinese manufacturing industry is "large but not strong," still highly dependent on foreign countries for high-end equipment, struggles with positive branding, and uses resources wastefully.[175] To remedy these issues, the plan outlines ten priority sectors (see table 5 below).

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[170] Stone & Wood. *China's Military-Civil Fusion Strategy,* p. 8.
[171] Cheung, Naughton & Hagt. *China's Roadmap*, p. 72.
[172] Tai Ming Cheung. *National Strategic Integration: How China is Building Its Strategic Power* (IGCC and MERICS, October 2023).
[173] Evron & Bitzinger. *The Fourth Industrial Revolution and Military-Civil Fusion,* p. 124.
[174] Rebecca Arcesati, François Chimits & Antonia Hmaidi. *Keeping value chains at home* (MERICS, 2024): p. 13.
[175] *Notice of the State Council on the Publication of "Made in China 2025."*

Table 5. 10 strategic priority areas of MIC25.

New-generation IT industry	High-end CNC machines and robots	Aviation and aerospace equipment	Offshore engineering equipment and high-tech ships	Advanced rail transportation equipment
Energy-saving and new-energy vehicles	Electrical equipment	Agricultural machinery and equipment	New materials	Biotech and high-performance medical devices

MIC25 addresses the CCP's concerns about economic growth stagnation, tech-dependency, and sustainability—all the while advancing China's claim to global technology leadership. Its clear market-orientation and dedicated government support to small- to medium-sized enterprises are distinctive (a spin-off policy, the "Little Giants" initiative, followed in 2018, providing more than 10,000 SMEs with government support to foster innovation).[176] In addition to the fact that several of the prioritised areas have military-civil dual-use potential, the MIC25's defence twin, the Defence Science and Technology Industry 2025 Plan, reportedly prioritises the development of space, aviation, and shipbuilding technologies.[177]

5.1.2 The Innovation-Driven Development Strategy

The most significant S&T initiative in the Xi era is the promotion of innovation to national strategy in 2016. The Innovation-Driven Development Strategy (IDDS) places innovation at the heart of national development and provides nationwide strategic orientation for all innovation efforts through 2050.[178] Jointly launched by the very highest levels of party and government, the IDDS is an extremely authoritative guidance document for the entire political system. It seeks to recentralise national S&T leadership and shares its position at the highest strategic level only with the Belt and Road Initiative.[179] A memorable line from the IDDS is "national prosperity follows from strength in innovation, and national misfortune follows from weakness in innovation." This is motivated in reference to the challenges to sustain economic growth, enhance national defence, address environmental and social sustainability, improve China's international status, and to catch the technological revolution.[180]

The IDDS sets out three central goals. The first is to become an innovative country by 2020 (a goal carried over from the 2006 MLP), defined as making breakthroughs on major bottlenecks and advancing some industries to the higher end of

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176 Sarah Mujeeb. China Is Betting Big on Its "Little Giants." *The Diplomat* (2024-08-08).

177 Cheung. *Innovate to Dominate*, p. 181; Cheung et al. *Planning for Innovation*, pp. 121–122.

178 *Outline of the National Innovation-Driven Development Strategy.*

179 Cheung. *Innovate to Dominate*, p. 30; Stone & Wood. *China's Military-Civil Fusion Strategy*, p. 37; Siwen Xiao & Yaosheng Yu. *(Re)Centralization: How China is Balancing Central and Local Power in Science, Technology, and Innovaiton* (IGCC & MERICS, March 2024).

180 *Outline of the National Innovation-Driven Development Strategy.*

global value chains. The second step is for China to become a leading innovation country with a "major increase" in international competitive strength by 2030. This is defined as leading global S&T development in certain strategic fields, reversing the dependency relationship so that other nations will become dependent on Chinese inventions, and generating original achievements that have "important effects on the development of the world's technology and the progress of human civilisation," expressing a clear interest in global S&T governance. The end goal is to become a world S&T innovation superpower by 2050 to support national rejuvenation. This is broadly defined as becoming one of the world's main centres (read: overtaking the US) for science, with world-renowned universities, innovative enterprises, and technological skill, especially in defence.[181]

To these ends, the strategy provides guidance for actors at all levels in society and for many specific technological areas (that largely overlap with MIC25). A key task is sharing knowledge in the civilian and defence economies; in other words, diffusion. Aside from its central role in the CCP's communication of strategic priorities, the IDDS is remarkable in that it encompasses more sectors than previously and gives unprecedented importance to market dynamics in "state-led, demand-driven, and market-oriented" innovation. The market orientation is clear in statements such as "with respect to development of new technologies. . . of a competitive nature, decisions should be made by markets and enterprises." [182] The IDDS also emphasises public-private partnerships and "mass entrepreneurship."

5.1.3 Artificial Intelligence Development Plan

The 2017 New Generation Artificial Intelligence Development Plan (AIDP) forms the core of China's AI strategy: to become the world leader in AI by 2030.[183] The plan highlights military-civil fusion to ensure that corporate and civilian advances in AI benefit national defence construction. The document describes AI as the "new engine of economic development," as a tool to forecast and pre-empt bouts of social unrest, and as an opportunity for China to build its first-mover advantage. In 2024, the AIDP was complemented with the "AI Plus" initiative to promote the "in-depth integration of AI and the real economy."[184] Critically, MCF seeks to harness military AI for command and control, intelligence processing, targeting, and so on.[185] On the topic of defence technology development, Tai Ming Cheung assesses that China has yet to transform from an "imitator" to an "innovator," though the quality of the nation's defence R&D has improved significantly since the early 2000s.[186] In 2016, Xi initiated reforms urging the PLA to "actively seek advantages in military technological competition." While the specific research

[181] *Outline of the National Innovation-Driven Development Strategy.*
[182] Cheung et al. *Planning for Innovation,* pp. 39–40.
[183] PRC State Council. *Next Generation Artificial Intelligence Development Plan* (2017).
[184] Global Times. China to launch AI Plus initiative: Government Work Report (2024-03-05).
[185] Evron & Bitzinger. *The Fourth Industrial Revolution and Military-Civil Fusion*, p. 47 & 112–113.
[186] Cheung et al. *Planning for Innovation*, p. 23; Cheung. *Innovate to Dominate*, pp. 22 & 178–180.

areas are unknown, the PLA launched several engineering projects of “pivotal strategic significance” in 2016–2020.[187] Given the Military Strategic Guideline on intelligentised warfare, these most likely strive to field military AI.

5.1.4 14th Five-Year Plan

S&T policymaking of course occurs in parallel with normal economic planning in the form of five-year plans (FYP). The FYPs normally include multiple sub-plans for various projects and industries and since 2016, the plans dedicate more and more space to technology, innovation, and security issues. The 13th and 14th FYPs (2016–2025) unsurprisingly reiterated the importance of innovation and the need to push ahead with structural reform, boosted R&D spending, etc.[188] These plans also called for improved applications of research results in manufacturing.[189]

5.2 Analysis of policy measures

Each S&T policy plan contains multiple policy measures, i.e. the instruments established to implement the policy (referred to in policy language as “strategic tasks” or “action agenda”). These can be more or less concrete. The policy documents typically assign each policy measure a number and then concretise the steps necessary to implement the task into one or several action items. Action items are sometimes given a number but are often simply structured into paragraphs.[190] Given the extensive length of the policy plans (see table 6 below), it was not feasible to categorise every measure. Due to the supreme significance of the IDDS, however, all of the IDDS’s eight strategic tasks were analysed. For the other plans, the analysis selected the policy measures that most clearly correspond to an innovation stage.

Table 6. Scope of analysed policy plans.

Policy plan	Total number of policy measures
14th FYP	92
AIDP	28
MIC25	16
IDDS	8

[187] Cheung. *Innovate to Dominate*, pp. 163 & 185.
[188] For a detailed review, see Cheung, Naughton & Hagt. *China’s Roadmap.*
[189] Cheung. *Innovate to Dominate*, p. 306; Jörg Mayer & Huifeng Sun. “Manufacturing Power Strategy: Advanced Manufacturing.” In Xiaolan Fu (ed.) *Oxford handbook of China innovation* (Oxford University Press, 2021): p. 698.
[190] See the appendix for an example of a typical Chinese innovation policy document structure.

Table 7, below, classifies a selection of various policy measures contained within the respective policy plans into the corresponding stage of the innovation process model, expressed schematically in the four rightmost columns of the chart. The classification of the policy measures into innovation stages is done by comparing a given measure with the four stages of the innovation process model and qualitatively assessing which stage is most comparable and compatible. This exercise is not entirely clear-cut. Although the classification choice is straight-forward in some instances, for many policy measures there is considerable overlap between apparent corresponding innovation stages, not least because policy measures typically include multiple action items that address a wide range of issues: some are very specific and limited to a certain task, while others are very sweeping or express far-reaching and ambitious intent. In instances where there is such overlap, the analysis selects the action item(s) that present the clearest match. In the case of the IDDS, two policy measures included such a mixed bundle of action items that the measure was assigned two innovation stages (see Table 7). Each box in Table 7 presents a policy measure in quotation marks (exactly as given in the plan), together with a brief summary of the measure's central content presented in italics to provide the motivation for the choice of interpretation and categorisation. Recall that the innovation stages are defined as:

- *Invention* is the creation of a new idea or technology or the use of an existing idea or technology in a new way to solve a problem.
- *Incubation* is an invention gaining status and influence throughout an organisation.
- *Implementation* is the process when the invention is adopted and applied throughout an organisation.
- *Diffusion* is the spread of the invention to other organisations or parts of the economy.

The classification was based on the same logic as in Chapter 3, namely, policy measures that seek to facilitate the production of new knowledge by addressing institutions, human and economic resources, research quality, and so on are categorised as "invention." Measures that seek to set out the initial steps towards applying the new knowledge/innovation are categorised as "incubation." Measures that pertain to the deployment of S&T innovation to create new capabilities are categorised as "implementation." Finally, measures that aim to widely spread and advance the effects of the innovation across a broader range of entities or industries in society are categorised as "diffusion." Some overlap occurs between "implementation" and "diffusion": in how many places or how widely should an innovation be implemented before it may be considered "diffused"? This study interprets the "diffusion" threshold to be relatively high, requiring a wider, cross-sector, and broad-based implementation in society (compared to an enterprise-level, sector-level, or regional-level implementation). The results are presented below.

Table 7. Selected examples of policy measures in the 14th FYP, AIDP, and MIC25, with corresponding innovation stages.[191]

Policy plan	Policy measure			
	Invention	Incubation	Implementation	Diffusion
14th FYP	"Consolidate and optimise S&T resource allocation" *Establish new laboratories, share resources among research institutes*	"Improve the technological innovation capability of enterprises" *Boost practical applications of research results in manufacturing*	"Deepen the implementation of the manufacturing powerhouse strategy" *Implement intelligent technologies to transform traditional industries*	"Accelerate the pace of digital-society construction" *Full integration of digital technology into social communication and daily life*
AIDP	"Build open and coordinated AI science and technology innovation systems" *Advance research, invent technologies, foster AI talent*	"Strengthen military-civilian integration in the AI domain" *Establish mechanisms to normalise coordination among military-civilian actors, promote all kinds of AI tech*	"Fostering a high-end, highly efficient smart economy" *Develop new AI industries, boost industrial intelligentisation*	"Construct a safe and convenient intelligent society" *Intelligentisation of the entire society. Smart cities, intelligent government, intelligent health care, etc.*
MIC25	"Promote the deep integration of informatisation and industrialisation" *Development of new-generation IT and manufacturing technology*	"Promote the deep integration . . ." *Formulate a roadmap for the integrated development of the internet and manufacturing; implement pilot projects for industrial big data*	"Improve national manufacturing innovation capabilities" *Accelerate the industrialisation of S&T achievements through improved incentive mechanisms*	"Improve the level of internationalised development of the manufacturing industry" *Accelerate the globalisation of enterprises; encourage the transfer of advanced technology overseas*

[191] Xinhua News Agency. *Outline of the People's Republic of China 14th Five-Year Plan for National Economic and Social Development and Long-Range Objectives for 2035* (CSET Translation, 2021); PRC State Council. *Next Generation Artificial Intelligence Development Plan* (DigiChina Translation, 2017); PRC State Council. *Notice of the State Council on the Publication of "Made in China 2025"* (CSET Translation, 2022).

Table 8. A classification of the eight strategic tasks of the IDDS.[192]

Policy measure	Innovation stage	Explanation
Promote innovation in industrial technology systems and create new development advantages	Invention	Focus on the development of new technologies
Strengthen original innovation and enhance sources of supply	Invention	Focus on enhancing research quality
Optimise the regional layout of innovation and create regional economic growth poles	Implementation	Focus on applying new innovation in regional manufacturing
Deepen military-civil fusion and promote interaction for innovation	Invention	Focus on boosting dual-use S&T innovation, integration of military-civilian standards
	Implementation	Coordinated civil-military practical applications
Enlarge innovation entities and lead in the development of innovation	Invention	Develop technologies, promote enterprise R&D, establish world-class universities
	Diffusion	Construct a nationwide technology transfer system
Implement significant scientific and technological projects and engineering works and make key leaps ahead	Invention	Focus on the development of new technologies
Establish teams of high-level talent and build a foundation for innovation	Invention	Focus on human resources
Promote innovation and entrepreneurship and stimulate the creative vitality of the whole society	Invention	Focus on creating an institutional and economic environment conducive to innovation activity by all

The key takeaway from the analysis is that the examined S&T innovation policies do contain measures to stimulate each of the four stages of the innovation process, as is shown in Table 7. However, the stages are not given equal attention. Table 8 shows this clearly. Even though it was not possible to analyse all measures, the authors' impression while going through the material is that a clear majority of the outlined tasks pertain to the invention stage: the development and invention of new knowledge and technologies. This takes several different forms, but generally there is a strong focus on creating the right institutional environment and economic preconditions for innovative activity, fostering talent, and removing barriers that could inhibit creative thinking and knowledge production, as well as measures focusing on the development of specific strategic technologies.

There are different possible interpretations of the reason behind the major focus on invention in current Chinese innovation policymaking. One interpretation is that invention measures are the most straightforward to carry out, as well as the

[192] Central Committee of the CCP & PRC State Council. *Outline of the National Innovation-Driven Development Strategy* (CSET Translation, 2019).

easiest and most rewarding to measure. Constructing a nationwide technology transfer system is quite clearly a more complicated (and likely also a more resource-intensive and high-effort) task than boosting R&D funding. Considering that innovation rankings carry great international prestige and convey status, investing in measures that are more likely to immediately raise the state's ranking (e.g., pursuing patents and academic paper citations) would appear to be a rational way to get the most value out of the invested resources in the context of S&T innovation as a tool for national power. Moreover, the complicated authority structures in the Chinese bureaucracy mean that economic actors tend to prefer actions that lead to "immediate. . . and material results" to gain political rewards.[193]

Another interpretation is that Chinese national-level policymakers understand the innovation process in linear terms, i.e. believing that innovation is done in a strictly sequential manner: invention first, and the other three stages later. However, the lack of attention to the later stages could impede the natural and organic rhythm of innovation as an ongoing process that relies on constant feedback from various actors in the network. While it is true that an invention needs to be invented before it can be incubated, implemented, and diffused, reasonably this process may occur in parallel for many different inventions all at once, rather than seeking to mature innovations in bulk or in sync as per a decided time frame.

Additional findings are that the second most common policy measure type appears to be that which stimulates implementation, that there are fewer concrete measures to stimulate incubation, and *very* few policy instruments for stimulating diffusion. In the IDDS, the authors could not identify one clear measure corresponding to the incubation stage of the innovation process (see Table 7 above). It is possible that classified S&T plans (such as the new 2020–2035 MLP) contain a higher degree of incubation, implementation, and diffusion-stimulating measures. The present geopolitical climate does provide incentive to keep certain tactics close to one's chest. It is also possible that local or regional policies are the primary channels for incubation and implementation measures, given that lower levels of government are closer to where the process unfolds.

The skewed distribution of attention in national-level policy across the innovation process is nevertheless interesting. One reason for this is the parallel to other major undertakings in China's not-so-distant past. Horowitz and Pindyck note that "a country may be able to skip or short-cut stages, depending on its bureaucratic process and prior progress."[194] Overall, what is distinctive for the Chinese model of innovation appears to be precisely this kind of logic, leapfrogging not only technological development but also stages in the innovation process. The concept of "leapfrogging" has been prevalent in Chinese views on national development, most prominently during the Great Leap Forward. Mao Zedong (in)famously

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[193] Breznitz & Murphree. *The Run of the Red Queen,* p. 44.

[194] Michael C. Horowitz & Shira Pindyck. What is military innovation and why it matters. *Journal of Strategic Studies*. 46:1 (2023): p. 102.

sought to transform China from an agrarian economy into an industrial power *immediately*, cutting the intermediate steps of gradually constructing a modern national economy. As has been well-documented elsewhere, the campaign led to mass famine and humanitarian catastrophe.[195] More recently, and far more successfully, mobile payment apps have largely replaced cash-based transactions, skipping the stage of widespread credit-card usage altogether.[196]

5.3 Implications for the Chinese innovation system

Based on the above results and interpretations, this section seeks to look into how China's national-level S&T policymaking plays upon its systemic strengths (described in Section 4.4).

Positive public perceptions

While the Chinese public's general appreciation of new technology should benefit incubation and implementation, inventions need to be introduced to the user base in order for them to gain status, influence, and mature into innovations. As we learned above, Xi's policies focus greatly on invention, stimulating the supply-side of innovations more than the demand-side (i.e., enhancing the status among a user base). Otherwise put: people cannot adopt, use, or share inventions that they do not know exist. The lack of political attention to incubation risks throttling the potential for inventors to gain feedback and learning experience in relation to the new invention, which is critical for it to mature and eventually generate productivity, security, and political gains.

On the one hand, the CCP leadership exhibits a theoretical understanding that building innovation capabilities and achieving the effects takes time (e.g., as visible in the adoption of long-term plans). But on the other, they also show a lack of patience with the slow pace of bottom-up processes to incubate new inventions and organically find applications and appreciation in a user base by pushing directly towards implementing and commercialising novel results. The implementation and diffusion of inventions across the whole of society, as is the ultimate end goal of the IDDS and other policies (see for example the "intelligentisation of society" in the AIDP), is undoubtedly important. Still, past policy mistakes show clearly the risks of rapidly pushing through major initiatives without taking time to reflect upon the progress. While rushing ahead, decision-makers may overlook signals that things may not be proceeding as planned. To raise one potential challenge in the economic domain, a recent study by the Mercator Institute for

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195 Lieberthal. *Governing China*, pp. 103–105.

196 Yiping Huang, Xue Wang & Xun Wang. Mobile Payment in China: Practice and Its Effects. *Asian Economic Papers.* 19:3 (2020).

China Studies concludes that Xi Jinping's policymaking creates ripe conditions for systematic overinvestment, overcapacity, and overproduction.[197] The study finds that subsidies and R&D support are common drivers of overcapacity risks in high-tech manufacturing industries. As such, a potential outcome of inventing for the sake of invention without also creating sufficient demand is reduced profitability or even loss-making on a major scale.

Big science and a big market

The substantial public funding, large skill base, and significant market potential provide both good preconditions and incentives for innovation. However, China's invention-heavy policy approach may encounter significant obstacles in a changed economic environment. To begin with, Beijing may need to adjust its practice of investing large sums of government renminbi in technology-push policies. Sustaining funding at the current level until 2050 (the deadline set for becoming an S&T superpower) will likely prove challenging in the "new normal" economic climate of protracted low growth rates. Recession means restrictions on government expenditures: the question is to what extent the CCP leadership will prioritise S&T spending above other expenses. While science-related prestige often pushes states to spend more than they can afford on R&D, an economic slowdown will nevertheless increase the pressure on commercial enterprises to take a larger responsibility for funding their own innovation activities. The dilemma is of course that a slower economy leaves less profit for the firms to reinvest.[198]

Additionally, economic stagnation affects consumer preferences. The "state-led, demand-driven, and market-oriented" innovation paradigm tells us that market demand from end-users drives the pace and direction of innovation activities. Even though all PRC citizens are encouraged to engage in "mass entrepreneurship" and support national S&T efforts through consuming domestically-produced products and services, with thinner wallets, civilian and military consumers' purchasing power and demand will likely decrease. While this could incentivise innovation in low-cost segments (potentially improving the efficiency of various technologies) as consumers seek less expensive alternatives, economic actors reasonably will view basic research and resource-intensive R&D as less worthwhile.

Finally, the demographic characteristics of the Chinese population, which in its large size and abundance of well-educated technical personnel, seemingly benefit invention. Indeed, to realise the strategic vision of technological self-reliance, the PRC is investing greatly in cultivating, attracting, and retaining the skilled human

[197] Jacob Gunter, Alexander Brown, François Chimits, Antonia Hmaidi, Abigaël Vasselier & Max J. Zengelein. *Beyond overcapacity: Chinese-style modernization and the clash of economic models* (MERICS, April 2025).

[198] Godin. Measurement and Statistics on Science and Technology: pp. 7–9; Camille Boullenois, Agatha Kratz & Laura Gormley. *Spread Thin: China's Science and Technology Spending in an Economic Slowdown* (Rhodium Group, December 2023).

capital necessary for high-end technological innovation. Xi Jinping has declared talent a "strategic resource to achieve national rejuvenation and win the initiative in international cooperation."[199] However, although elite scientists are necessary for invention, the Chinese populace as a whole lacks other key demographic qualities that benefit incubation, implementation, and diffusion. Most prominently, the PRC's underinvestment in national primary and secondary education greatly restrains the cumulative buildup of broad-based human capital of the kind needed to widely circulate and implement new knowledge.[200] In 2023, the PRC's level of upper secondary attainment among 25–64-year-olds was the second lowest among OECD countries at 36.6 percent: i.e., less than four out of ten Chinese adults have graduated from high school.[201] This implies that China will face immense difficulty in finding qualified labour to work in high-tech environments, thus restraining the nation's ability to push its economy to high-income levels with implications for its economic power and political legitimacy. In terms of security, the PLA may struggle to recruit enough soldiers who are sufficiently educated to operate complex military systems. Insufficient talent supply will impede the diffusion of new technologies across society—meaning that the CCP's aim of transforming China into an "intelligentised society" risks isolating substantial portions of the population who are less likely to know intuitively how to navigate digital systems. In turn, this may reinforce existing educational divides and urban-rural wealth gaps, further capping the national talent supply.

Competitive innovation and the role of private businesses

Private businesses have played an important role in driving China's innovation as a means to stay competitive. To some extent, innovation by business-minded entrepreneurs to meet consumer demand (both civilian and military) is expected to offset decreasing government S&T funding: in 2023, direct government subsidies constituted around 17 percent of overall national funding for science and research—a considerable drop from 71 percent in 2003. As an approach to pushing economic actors to become more attuned to consumer demands and invest their resources accordingly, this could be a good call. However, the injection of market logic in national R&D efforts and the call for "mass entrepreneurship" amplifies the pressure on S&T personnel to not only be good researchers and engineers, but also to venture outside of their core competence areas and be business-minded entrepreneurs. While individual researchers may excel in both parts, in many cases this shift in priorities forces researchers to set aside their core skills and interests

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[199] Xi Jinping as quoted in Briana Boland, Kevin Dong, Jude Blanchette, Ryan Hass & Erica Ye. *How China's Human Capital Impacts Its National Competitiveness* (CSIS, June 2024): p. 1.

[200] Scott Rozelle & Natalie Hell. *Invisible China: How the Urban-Rural Divide Threatens China's Rise* (University of Chicago Press, 2020).

[201] OECD. "China: Overview of the education system" (2024).

to develop marketable products. In some cases, this has yielded science that is "fragmentary at best and practically ineffective or even harmful at worst."[202]

In the defence sector, the market-driven innovation paradigm could prove even more consequential. Defence-technology development in the PRC has historically been initiated by top-down targeted development based on identified military needs. The Megaprojects of the Mao and Hu eras exemplify this neatly, showing how the political leadership assigned top priority to certain selected areas to counter perceived threats. More recently, the PLA's risk assessment of cyber and intelligent warfare has led the CCP to put forth policies pushing the technological development of autonomous systems, artificial intelligence, big data, etc. This style of technology development for natural reasons involves an intentional and highly structured process of invention, where government policies play a big role in directing national S&T efforts.[203] While the defence sector likely will retain much direct state intervention in its industrial activities, it is clear that the CCP wishes (state-owned and private) defence manufacturers, too, to act more like business-minded corporations.[204] The issue is that China's arms producers do not compete for sales in the same manner as firms on the civilian market do since the defence market is oligopolistic and the major producers have a monopoly in their respective market segment.[205] Being the sole producer in a given segment means that there is less incentive to reinvest profits in R&D (at the expense of gaining a larger profit) to create improved products and processes, since there is no need to compete for the consumer's (there is only one consumer, the PLA) attention.

[202] Greenhalgh. Governing Through Science, pp. 11–12 & 16.

[203] Harting et al. *Comparative Analysis of U.S. and PRC Efforts*, pp. 22–23.

[204] See for example Frida Lampinen. China's defence industrial base. In Oscar Almén & Christopher Weidacher Hsiung (eds.). *Studying China's Military Power: Analytical framework and methods* (FOI, forthcoming).

[205] Sarah Kirchberger & Johannes Mohr. China's defence industry. In Keith Hartley & Jean Belin (eds.) *The Economics of the Global Defence Industry* (Routledge, 2019).

6 Conclusions and discussion

This report seeks to provide nuance and context to the discussion surrounding Chinese innovation capacity and the race for technological dominance between China and the West. By drawing on innovation theory, the report separates innovation into four separate stages: invention, incubation, implementation, and diffusion. The variables in three quantitative reports that study US/Western and Chinese innovation capacity are compared to the four innovation stages. The result shows that most variables used to compare countries' innovative capacity specifically look at the invention stage of innovation. Sometimes diffusion is also measured, whereas incubation or implementation are hard to measure quantitatively and thus receive less attention.

All four stages of the innovation process provide useful information regarding a nation's innovation capacity. It is worth noting, however, that the stages do not necessarily have to correlate. A country can be skilled at the invention stage of innovation, but less skilled at implementation or diffusion, or vice versa. Focusing too much on the invention stage of innovation capacity can thus give us an incomplete or misleading picture, particularly since some academic literature indicates that China is stronger at invention than diffusion.[206] Studies also indicate that how a technology is introduced and applied in an organisation has a great impact on how well the technology contributes to affecting the balance of power, further stressing the importance of understanding the incubation and implementtation processes. Thus, understanding incubation and implementation is important to understand innovative capability. This is particularly true in the military domain, where market forces typically drive the adoption of technologies to a lesser extent than in the commercial sphere, given that there is only one domestic consumer. Instead, issues such as compatibility of an innovation with military culture and differing effects of an innovation on different institutions can impact whether incubation and implementation are successful.[207]

To illustrate the necessity of incubation and implementation in a military context, it is possible to imagine several scenarios pertaining to military AI in which an incomplete innovation process may inhibit progress towards capability targets. If AI-integrated systems, for example, are fielded without sufficient incubation or through generic implementation policies that are not adapted to innovation process-specific circumstances, systems users may continue to prefer old equipment despite the top military leadership's eagerness to reap strategic benefits. While soldiers who do not receive enough training or time to acquaint themselves

[206] Ding. The diffusion deficit in scientific and technological power.

[207] Emily O. Goldman & Andrew Ross, The diffusion of Military Technology and Ideas – Theory and practice. Published in *The Diffusion of Military Technology and Ideas*. Eds.Emily O. Goldman & Leslie C. Eliason 2014

with new systems may feel uncomfortable and stick to earlier models out of habit, officers at the operational level may hesitate out of concern that the introduction of new weapons systems with steep learning curves may reduce their unit's immediate performance. Since incubation and implementation are hard to capture with quantitative variables, future research may want to explore qualitative tools to study these stages in order to broaden our understanding of the struggle for technological dominance.

Secondly, the report reviews three main strategic interests that underpin China's pursuit of S&T innovation, where a strengthened emphasis on security issues is defining for Xi's personal leadership. Chapter 4 presents a perspective on why China has been able to climb the innovation ladder, seemingly against all odds. Positive public perceptions, the pursuit of "big science" on a big market, and competitive entrepreneurship have likely played a part in driving China's successes, despite its state-permeated economy and authoritarianism. The study has not analysed how efficiently Beijing's S&T policies contribute to building China's innovation capacity, but it does provide a perspective on how Xi's S&T policymaking plays upon the systemic strengths of the PRC innovation ecosystem.

Xi's envisioned innovation trajectory, overall, begins with invention and concludes in diffusion. National policy measures less clearly define the stages in between. The central driving force for transforming inventions into generating economic, military and international political power effects is domestic market interests. In itself, this is nothing new, as private firms have played a major part since the economy opened up in the late 1980s. However, the lack of policy attention to ensuring the market is prepared to absorb new inventions, and that the consumer base is equipped with the necessary skills and resources to manage incubation, implementation, and diffusion without party-state guidance in a changing geopolitical, economic, and demographic environment seems short-sighted.

One of the aims of Chapter 5 is to explore whether a processual approach is useful to understand China's S&T innovation governance. The analysis indicates that PRC national-level innovation policies focus on stimulating invention and pay less attention to ways of maximising the benefits in incubation, implementation, and diffusion attainable by playing on the characteristics of the Chinese innovation system. Instead, inventions are largely expected to mature organically through market dynamics. This does not fully explain why China is strong in invention, and weak in diffusion, as Chapter 3 indicates. However, to the extent that it generates a new hypothesis that may orient future studies on the strengths and weaknesses of China's innovation efforts, the process-model perspective is useful.

6.1 Discussion

Where does China go from here? Will the PRC's systemic characteristics be able to continue to push its innovativeness, or is this as far as it can go? It appears clear that the Chinese leadership will continue to dedicate great efforts, resources, and attention to bolstering national innovation capacity as an instrument for achieving the rejuvenation of the Chinese nation and realising the CCP's three strategic objectives described above. The reasons for adhering to this dedication increase if we consider other incentives, based not on power dynamics, but on national identity. Recent scholarship has questioned the instrumentalist view of innovation as a means to a given end (be it national power, prosperity, or another), highlighting instead that a state's sustained commitment to S&T policy is valuable for national identities in and of itself. In other words, innovation in science and technology, pursued habitually over time, becomes a political process through which world order is created and maintained—meaning that S&T success becomes a necessary part in the way states imagine their "way of life."[208] Plausibly, a continued emphasis on innovation capacity and on technological achievements in official discourses on Chinese nationalism will worsen Beijing's threat perceptions. In pinning the CCP's legitimacy on the use of S&T to achieve national wealth, power, and global status, the stakes for succeeding are incredibly high.[209] The more significance that party rhetoric attaches to the PRC's technological success, the more prone China may become to react aggressively to perceived threats in international affairs, if S&T progress falls short of set goals.[210]

Amid these high stakes, the PRC's innovation performance faces several hurdles. A first potential bottleneck is technical expertise. Experts suggest China's access to foreign technology and knowledge will continue to be an essential factor for its S&T development for yet some time ahead.[211] China tries to compensate for this by using targeted acquisitions of know-how from abroad (as promoted in the IDAR strategy of the MLP and IDDS), for example, by direct investment, talent recruitment, and research collaborations.[212] However, in a harsher geopolitical environment (driven at least in part by Beijing's own foreign policy actions), China stands to lose access to an increasingly wide array of overseas opportunities in business, scholarship, investment, and other traditional sources of know-how.

In addition to setbacks in knowledge acquisition, a second challenge is ensuring innovation actors adhere to the party line. Although Xi's policies unequivocally emphasise the primacy of innovation and the need for all actors to pitch in, this

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[208] Daniel R. McCarthy. Imagining the security of innovation: Technological innovation, national security, and the American way of life. *Critical Studies on Security*. 9:3 (2021).
[209] Greenhalgh. "Governing Through Science," pp. 9–10.
[210] Wang. The "Techno-Turn."
[211] Cheung. *Innovate to Dominate*, p. 295; García-Herraro & Schindowski. *China's Quest for Innovation,* p. 22.
[212] Rühlig. *The Sources of China's Innovativeness,* p. 6.

mitigates but does not solve the political system's problems with parallel authority structures and multiplicity of interests. In recent years, several new regulatory bodies within the S&T realm have emerged, making the institutional framework even more complex.[213] In addition to complicated formal authority structures, anti-corruption campaigns are widespread in both the public and private sectors, and the party-state's clampdown on private enterprises has stirred up significant uncertainty in the S&T sector and in society more broadly.[214] Additionally, the tendency in public discourse to accredit innovation successes to the strengths of the system, rather than to brilliant individual performances, is unlikely to encourage mass entrepreneurship. Not only do Chinese youths exhibit a clear preference for civil servant jobs over private sector careers, the inconsistent reward structures suggest that corporate employees and civil servants alike may feel disinclined to take risks that, on the one hand, could generate innovation, but, on the other, could get them into trouble for interpreting directives incorrectly.[215]

Finally, the high pressure on the Chinese people to innovate may inversely impact innovation rates *negatively*. Scholars have argued that science in China today has arguably lost its original meaning, becoming instead the production of data shaped by political obligations.[216] When innovation is politicised, what does it mean to be—or not to be—an "innovative nation"?

For international peer competitors, the PRC's unevenly distributed policy attention across the innovation process raises several policy implications. First, it brings attention to the challenges that governments face in formulating innovation policy that plays on and reinforces the country's systemic strengths. Broad initiatives to create an institutional, economic, and political environment that benefits technological learning and risk-taking entrepreneurship in general are of course important. Still, a process-model perspective suggests that, for an effective and resource-efficient approach, policymakers should consider the strengths and weaknesses posed by the characteristics of the nation's innovation system *in each innovation stage*. For example, how does the system's propensity for invention complement or impede incubation, implementation, and diffusion?

Relatedly, a process model perspective suggests that, in the context of national power and strategic competition, a state's national innovation capacity is only as strong as its weakest innovation stage. A state looking to position itself competitively in the "fourth industrial revolution" may consider focusing its efforts to overtake competitors in the innovation stages where the competitor is struggling, depending on the state's aim in pursuing 4IR technologies. While being the first to develop a given technology has its benefits (such as getting to set the standard), it is questionable whether trying to outcompete China in the *invention* arena is the

[213] García-Herraro & Schindowski. *China's Quest for Innovation,* pp. 19–20.
[214] Rühlig. *The Sources of China's Innovativeness,* p. 11.
[215] García-Herraro & Schindowski. *China's Quest for Innovation,* pp. 19–20.
[216] Greenhalgh. "Governing Through Science," pp. 5, 16 & 18.

best course of action for most peer competitors. Clearly, Beijing is betting big on invention, and competitors will likely need to channel massive resources into R&D in S&T over the course of the next decade to keep pace. While in-house development may be necessary for certain technologies of national security and defence interest, for most generic technologies with productivity-enhancing properties, investments into winning the invention race are perhaps better spent elsewhere. For example, state actors with finite R&D resources may instead choose to invest in regional, cross-sectoral, or pan-governmental technology-sharing infrastructure; equipping the population with necessary skills (through universal education); or specialising in the manufacture of one or a few particular technologies (patented elsewhere), and in that way securing local jobs in a lucrative global supply chain.

6.2 Suggestions for future research

Finally, we identify five areas for future research to expand upon, substantiate, and generalise the findings of this report:

- Develop new variables for qualitative, repeatable, and theoretically valid measurements of incubation and implementation in the innovation assessment literature.
- Apply the analytical framework to other countries. How unique is the focus on invention in national-level S&T policy to China? Is this generally the case for most countries, or do some countries approach innovation policy differently?
- Build upon previous research on the relationship between threat perceptions and national innovation rates. While existing scholarship has found that countries perceiving a higher level of threat tend to innovate more over time, the Chinese case raises questions as to the relationship in reverse: whether a long-term, government-led emphasis on innovation capacity makes states more prone to perceive security threats and capability gaps more acutely.
- Delve deeper into the influence of expert advice on Chinese policy-making. For example, examining more closely the Chinese literature on innovation theory, such as by reviewing in detail the research tagged with “innovation process” or “innovation model” on CNKI, or looking into the specific profiles of experts and scholars involved in the drafting process.
- Examine the gap between the PRC’s innovation policy and its action: To what extent do Chinese enterprises (public and private, on the civilian and the defence markets) actually operate as innovation policy directives prescribe? What governance instruments does the PRC government employ to incentivise enterprises to “run the state’s innovation errands”? What does this imply for multinational corporations or firms with foreign ownership on the Chinese market?

7 References & appendix

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Appendix

Variable type	ASPI variables	ITIF variables	RAND variables
Talent flows	The study/work movement patterns between countries for researchers who wrote the 25% most-cited papers	—	—
Top institutions in a country	Number of research institutions a country has in the world's top 10–20 highest-performing institutions based on highly cited papers	Top-ranked universities in China relative to the United States, based on the Shanghai (academic) Ranking, and ITIF's own scoring method	Top publishing organisations within a focal field: a country's number of organisations with the most publications produced by authors affiliated with those organisations during the period of analysis; centrality of top publishing organisations within a collaboration network in a focal field: eigenvector centrality and degree centrality of top publishing organisations, based on a full collaboration network (of co-authorships); conferences within a focal field: a country's number of conferences that produce a report or conference proceedings and occur on a regular basis

Research centrality			Eigenvector centrality and degree for top 15 publishing organisations based on the full collaboration network (co-authorship) for the field in question
R&D expenditure and investment	—	China's gross R&D and components expenditures relative to the United States R&D intensity in China and the United States; China's R&D and component intensities relative to the United States	Number and descriptions of a country's official military development programmes for focal technologies; a country's public spending on a focal technology; qualitative assessment of a country's major critical technology; element-specific development activities
Top firms in critical fields	—	Chinese firms among the world's top R&D investors relative to the United States	Qualitative assessment of the development activities of a country's most important organisations in a focal field
Access to venture-capital investment by country	—	China's gross venture-capital investment relative to the United States; China's venture-capital investment as a share of GDP relative to the United States	—

Access to researchers	—	Number of researchers in China relative to the number in the United States; China's researchers as a share of total employment relative to the United States	Authors ranked in the top 0.1 percent for H-index for the 2013–2022 period: a country's number of authors whose number of papers (H) within a focal field have been cited at least H times
Population education level	—	Total undergraduate degrees awarded in China relative to the United States; undergraduate degrees awarded in China relative to the United States; number of science and engineering doctoral degrees awarded in China relative to the United States; number of doctoral degrees awarded per capita (25–39-year-old population) relative to the United States, 2010–2018	—
Quantity and quality of published papers	A country's proportion of the top 10% most-cited papers in chosen fields: the H-index	Number of science and engineering articles in China relative to the United States; number of science and engineering articles per capita in	Annual scientific publications within a focal field: a country's number of publications produced by authors from organisations located within that country

		China relative to the United States; share of Chinese science and engineering articles ranking among the top 1% globally in citations, relative to the United States	
Patents granted within relevant fields		Number of international patent families granted to Chinese entities relative to the United States; number of international patent families granted to Chinese entities per capita relative to the United States	Annual patent grant output within a focal field: a country's number of patents, based on the location of the patent assignee; number of patents awarded to a country's organisations in a focal field over the period of analysis; a country's number of patents pertaining to a critical-technology element
Patent receipts		Value of cross-border IP licensing receipts by Chinese entities relative to the United States; value of cross-border IP licensing receipts by Chinese entities as a share of GDP relative to the United States	

Production in and export from advanced industries	—	Chinese production in high-R&D industries relative to the US; China's value-added and export shares in R&D-intensive industries relative to the US; China's value-added in advanced industries relative to the United States; China's value-added in advanced industries as a share of GDP relative to the United States; China's exports in advanced industries relative to the United States; China's exports in advanced industries as a share of its total exports relative to the United States	—
Economic complexity	—	China's economic-complexity index score relative to the US.	—
Testing infrastructure (Wind tunnels, super computers, research vessels, particle	—	Chinese supercomputers among the top 500 relative to the United States (number of systems and	Number and descriptions of a country's major relevant S&T infrastructure activities

colliders, testing facilities, etc).		cumulative performance)	
robotisation	—	Industrial robot density in China relative to the US	—
Access to tele-communications and digital services	—	Number of mobile cellular and fixed broadband subscriptions in China relative to the US; number of mobile phone subscriptions per capita and fixed broadband subscriptions per household in China relative to the US; China's mobile-connectivity index score relative to the United States; China's E-Government Development Index score relative to the US	—
Cybersecurity	—	China's global cybersecurity score relative to the US	—
Fielded advanced military systems	—	—	Number and key technical specifications of a country's completed systems that leverage a focal critical technology area, including operational prototypes and acquisition

			programmes that have reached initial operational capability; quantity of fielded systems that a country's military has available; distribution of a country's assigned systems across military units
Weapons exports	—	—	Quantity and value of a country's foreign military sales of systems involving a focal technology
Technology transition.	—	—	Qualitative assessment of a country's ability to turn development activity into fielded military systems

Example of a typical Chinese policy document structure (from the AIDP)

Excerpt from policy document	Explanation of structure
3. Strategic tasks and priorities (1) Improve national manufacturing innovation capabilities:	Policy measure
Improve the system of manufacturing industry innovation that combines taking enterprises as the mainstay, being oriented toward the market, and involving government, industry, academia, research institutes, and users. Deploy the innovation chain around the industrial chain. Allocate the resource chain around the innovation chain. Strengthen key and core technology research, accelerate the industrialization of S&T achievements, and improve innovation capabilities in key links and key areas.	Action task
Strengthen research and development of key and core technologies. Strengthen the mainstay status of enterprises in technological innovation, support enterprises that improve their innovation capabilities, promote the construction of national technological innovation demonstration enterprises and enterprise technology centers, and fully absorb enterprises to participate in the decision-making and implementation of national S&T plans. Aiming at the country's major strategic needs and the commanding heights of future industrial development, routinely research, formulate, and release roadmaps for technological innovation in key areas of manufacturing. Continue to	Action task

implement major national S&T projects without delay and support key and core technology R&D through national S&T plans (special projects, funds, etc.). Give full play to the leading role of industrial backbone enterprises (行业骨干企业) and the basic role of institutions of higher education and scientific research institutes. Establish a group of industrial innovation alliances and carry out collaborative innovation by government, industry, academia, research institutes, and users. Achieve breakthroughs in a number of key general purpose technologies that have an overall impact and strong driving force on the overall improvement of industrial competitiveness, and accelerate the conversion of S&T achievements into practical applications.	
Improve innovative design capabilities. Carry out innovative design demonstrations in key fields such as traditional manufacturing, strategic emerging industries, and modern service industries, and comprehensively promote the application of advanced design technologies characterized by eco-friendliness, intelligence, and collaboration. Strengthen the research and development of general purpose core technologies in the design field, achieve breakthroughs in general purpose technologies such as informatized design, process integration design, and complex process and system design, develop a batch of key design tools and software with independent intellectual property rights (IPR), and build and improve the innovative design ecosystem. Build a number of innovative design clusters with global influence, incubate a group of professional and open industrial design enterprises, encourage original equipment manufacturer (OEM) enterprises to establish research and design centers, and shift to designing products for others and exporting independent brand products. Develop various types of innovative design education formats, establish national industrial design awards, and stimulate the enthusiasm and initiative of the whole of society for innovative design.	Action task
Promote S&T achievement industrialization. Improve the operating mechanism for the conversion of S&T achievements into practical applications, study and formulate guidelines for promoting the conversion and industrialization of S&T achievements, establish and improve the information release and sharing platform for S&T achievements, and improve the technology transfer and industrialization service system centered around technology trading markets. Improve the incentive mechanisms for the conversion of S&T achievements into practical applications, promote the reform of the use, disposal, and income management of S&T achievements in public institutions, and improve the scientific evaluation and market pricing mechanisms for S&T achievements. Improve the collaborative promotion mechanism for the conversion of S&T achievements into practical applications, guide government, industry, academia, research institutes, and users to strengthen collaboration in accordance with the laws of the market and the laws of innovation, and encourage enterprises and social capital to establish a number of pilot bases for technology integration, maturation, and engineering. Accelerate the conversion and industrialization of national defense S&T achievements and promote the two-way transfer and conversion of military and civilian technologies.	Action task

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