Research Report

CORTNEY WEINBAUM, CAOLIONN O'CONNELL, STEVEN W. POPPER, M. SCOTT BOND, HANNAH JANE BYRNE, CHRISTIAN CURRIDEN, GREGORY WEIDER FAUERBACH, SALE LILLY, JARED MONDSCHEIN, JON SCHMID

Assessing Systemic Strengths and Vulnerabilities of China's Defense Industrial Base

With a Repeatable Methodology for Other Countries

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About This Report

This report presents an assessment of the strengths and vulnerabilities of China's defense industrial base (DIB), conducted to meet a congressional requirement set forth in Section 1260C of the Fiscal Year 2021 National Defense Authorization Act. We developed a methodology that can be applied to any country to assess the strengths and vulnerabilities of that country's DIB. The initial assessment was applied to the People's Republic of China. Application of the methodology revealed several strengths and vulnerabilities in China's DIB and several areas in which China is reliant on the United States and U.S. allies. Additionally, we identified several information requirements that would improve this assessment based on the open-source data available.

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Summary

In this report, we examine the strengths and vulnerabilities of China's defense industrial base (DIB), to meet a congressional requirement set forth in Section 1260C of the Fiscal Year 2021 National Defense Authorization Act (NDAA). To conduct the assessment, we designed a methodology that can be applied to any country to assess the systemic strengths and vulnerabilities of that country's DIB; our initial application is to the People's Republic of China (the "PRC" or "China"), as requested in the NDAA.

Approach

Hundreds of studies exist on foreign DIBs, including dozens of studies on China's DIB. We identified, collected, and examined a subset of these studies to create a repeatable methodology that could be applied to any country, with the first application being to China. We used both primary and secondary sources, which we cite throughout the report. We examine China's DIB across six topics: economics; governance and regulations; research, development, and innovation; workforce, labor, and skills; manufacturing; and raw materials. This summary provides our overarching insights about China; the rest of the report contains our assessment of China's DIB across these six topics. The new methodology we developed is presented in Appendix B.

Strengths and Vulnerabilities of China's DIB

Our study revealed several strengths and vulnerabilities in China's DIB and several areas in which China is reliant on the United States and U.S. allies.

The Sheer Size of China's DIB Makes It Relatively Opaque to Outsiders and Unwieldy for the PRC

China's DIB is extensive,[1] making an examination of deep structural problems difficult for outside analysts. Lack of transparency is another limitation, as it is in any closed society, but this challenge is exacerbated by our assessment that in some areas even China's central government lacks transparency into its own state-owned enterprises (SOEs) and other DIB suppliers. Lack of transparency is not merely our own difficulty; it is China's as well.

This lack of transparency makes it difficult to assess the relationships between and among firms inside and outside the DIB, including SOEs and other types of enterprises and organizations in dual-use sectors. China's system of *guanxi*—the network of social relationships

[1] Of the top 20 defense-related firms worldwide, seven are Chinese state-owned enterprises.

used to facilitate management, business deals, and party directives—is opaque to outside observers. These relationships—including at the individual person and firm level—would illuminate why certain firms receive favor in the DIB, including beneficial contracts. As managers move between firms and officials move between the Chinese Communist Party (CCP) and positions throughout the DIB, *guanxi* is among the strings being pulled from behind the scenes. A greater understanding of these relationships and favors would provide insights that are currently not even known to many within China's DIB who themselves may lack visibility into relationships they are not personally party to.

Additionally, we were unable to find research that adequately described the nature of what it means to be a "privately owned enterprise" (POE) in China and POEs' role in the DIB. In the United States, this concept is clear, but we chose not to apply our U.S. definitions (or mirroring bias) to China's enterprises. A greater understanding of the nature, ownership structure, organization, and other elements of China's POEs would benefit future users of our methodology, as well as U.S. policymakers.

China's DIB Both Benefits and Suffers from the Effects of Single-Party Dominance of Government

The centralization of power and decisionmaking within the Chinese government supports its ability to drive whole-of-government strategies, set priorities, and align government actions around its priorities in ways the U.S. government is unable to do. China can create global approaches to its priorities, whereas the U.S. government must take more fragmented or piecemeal actions in the absence of affirmative interagency processes. But the ability of the Chinese government to lead with one voice creates a weakness for the country when the entire DIB pivots toward the new priorities to the detriment of others. In short, Xi Jinping can do anything, but he cannot do everything. Topics outside the priority list risk anemic treatment without the leadership's spotlight. This challenge is a risk for China should the government bet on the wrong technology or shine its light too brightly on one aspect of its DIB and leave another in the dark.

This challenge for China is exacerbated by the CCP's recent activities to exert greater central control on market-oriented reforms. The Party, led by Xi, risks inhibiting innovation by fostering an environment in which entrepreneurs avoid potential reproach by leadership. In general, the mutual desire for both (1) influential party control employing cadres and campaign approaches to achieve goals on the one hand and (2) a more entrepreneurial, innovative managerial culture on the other may be one of the most meaningful contradictions that might roil under the surface of the DIB in the coming decade.

China Is a Global Science and Technology Power, Yet the Chinese Defense Innovation System Suffers from Weak Linkages Between Elements and Dependency on Foreign Inputs

China is no longer an "emerging" science and technology (S&T) power; rather, it is competing with the United States for global S&T primacy. On measures of scientific output, China and the United States compete closely for the top ranking. In patented military technology, China has a quantitative advantage relative to the United States, even after adjusting for patent quality.

However, China's defense innovation system suffers from weak linkages between system components. Linkages among government S&T organizations, enterprises, and research organizations are observed to be weak, indicating that the system does not effectively transmit knowledge and information between components. China's defense innovation system also remains dependent on foreign countries—including the United States and U.S. allies—in many areas, including education, material imports, and intellectual property (IP). The sheer scale of China's practices for gathering these resources—education and IP—from foreign countries indicates the country's own view of these areas as domestic vulnerabilities.

Although China's Manufacturing Capacity Looks Strong, There Are Clear Dependences That Indicate Potential Weakness

China runs large trade deficits with East Asia and Europe in manufacturing. China is the world's leading importer of most bulk commodities, and there are high-tech imports that sustain the manufacturing base.[2] As the "world's workshop," China imports intermediate goods and components to produce finished electronics, vehicles, and other goods. Additionally, there is a revealed dependence on imported computer numerical control (CNC) milling machines and precision measurement tools, such as photo-optical image readers, to allow China's automated manufacturing processes to function smoothly. These trade flows are an impetus behind the "Made-in-China 2025" plan to alleviate the growing volume of high-tech imports and prevent a shrinking trade surplus from turning into a deficit.

China's reliance on manufacturing imports places importance on a select few nations that have an oversized weight in China's trade portfolio. Among the top five manufacturing imports, different integrated circuit (IC) categories account for three of the five, vehicles account for a fourth, and biotechnology and pharmaceuticals (not bulk chemicals) account for the fifth category. South Korea, Taiwan, Japan, and the United States are significant players in the IC market, and ICs represent China's largest import category, exceeding even that of fuel and ore. In a sense, ICs are like the petroleum of the 20th century and the coal of the 19th century to China's economic engine. It may seem paradoxical that China also exports ICs in large numbers,

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[2] World Trade Organization, *Trade Profiles 2019*, 2019, pp. 80–81.

but China has leaned on highly developed East Asian economies to import smaller, more efficient ICs (currently at the 7-nanometer size) while exporting larger and more common ICs.

China's DIB remains dependent on Russia, Ukraine, and, to some degree, France for aircraft and naval engines despite China's efforts to develop the capability domestically. Indeed, engines as a category represented the largest share of all Chinese arms imports between 2015 and 2020.

China Will Be Vulnerable to Significant Workforce Upheaval over the Next Ten Years

China's labor force will shrink over the next two decades, as fertility rates continue to drop throughout Asia.[3] China's coming workforce pinch is complicated by its large population and the extreme income disparities between the coasts and the interior. These longer-term trends might create future challenges for China not only regarding sheer workforce size but also in shifts in bargaining power—both bargaining power considered narrowly with regard to wages and working conditions, and considered more broadly with increased pressure for social spending from a more slowly growing gross domestic product placing a squeeze on DIB procurement.

We found indications that China's DIB might struggle to attract and retain trained talent in the future. Research from Fudan and Tsinghua universities shows that a third of recent graduates, regardless of whether they were educated at home or abroad, quit their first job within six months of graduation because of unmet career expectations. SOEs make up the majority of the DIB, and though they have long been regarded as desirable employers, they are historically resistant to change, even when directed by CCP leadership. Assuming this trend holds true, DIB firms may struggle to meet the growing career expectations of the emerging workforce and as a result struggle to retain top-tier talent. It is possible that the growing campaign for military-civil fusion (MCF) along with a potential shift to more defense production coming from dual-use producers outside the traditional DIB could affect this balance by making the DIB SOEs relatively more attractive, the POEs less so, or both.

Suggested Information Requirements to Improve Assessment of China's DIB

Section 1260C also asked for identification of "intelligence and other information requirements" that might address foreign DIB strengths and weaknesses generally and for China in particular. In this section, we provide several information requirements that would improve these assessments—beyond those already noted in the prior section—based on the open-source data available.

When examining raw materials, we were unable to assess the size of China's stockpiles. Without the size of the stockpiles and information about the rate at which China uses a given

[3] One demographic driver, the modified One-Child Policy, has been considerably relaxed yet still remains on the books as a potential element of control (Junsen Zhang, "The Evolution of China's One-Child Policy and Its Effects on Family Outcomes," *Journal of Economic Perspectives*, Vol. 31, No. 1, Winter 2017).

material, we were unable to assess how long China can continue its current course or recover if the country lost access to any given material.

We found, in both secondary and primary sources, a lack of data and analysis about DIB firms that provide both services and software to the People's Liberation Army (PLA). In the United States, these firms frequently provide ongoing logistics support for major military systems, information systems, and other defense services. The same firms that provide products often also provide the services to maintain those systems, and we can assume that these same skills would reside in China's SOEs. But we lack data about the size of the DIB services components distinct from products, the services being provided and their quality, and whether the SOEs are providing services or the PLA is servicing its own systems.

We were unable to find data or analysis on the size and quality of the DIB software industry. For software that is tied directly to hardware systems—such as the guidance system for a missile—we could make certain assumptions about the software's quality based on the effectiveness of underlying hardware (e.g., accuracy). For software not associated with one system, such as applications for integration across command, control, communications, intelligence, surveillance, and reconnaissance (C4ISR) systems, we could draw no conclusions.

We found no systematic analysis of the flow of Chinese students and researchers out of China to foreign universities *and back*. Much research and analysis on this topic is anecdotal—using individual examples to understand common tactics—but these analyses prevent an understanding of how specific Chinese institutions or programs are engaging with specific non-Chinese institutions or programs to feed talent directly into the Chinese DIB.

Contents

Figures and Tables

Figures

Tables

1. Introduction

This report presents an assessment of China's defense industrial base (DIB), in which we examine the Chinese DIB's strengths and vulnerabilities with respect to China's ability to achieve its own goals. We conducted this assessment by creating a repeatable methodology for assessing a foreign DIB and then applying that methodology to the People's Republic of China (the "PRC" or "China"). This study was conducted to meet a congressional requirement from Section 1260C in the Fiscal Year 2021 (FY21) National Defense Authorization Act (NDAA).[4] As stated in the NDAA, the following specific elements were mandated by Congress:

1. examining the competitive military advantages of foreign adversaries, including with respect to regulation, raw materials, use of energy and other natural resources, education, labor, and capital accessibility
2. assessing relative cost, speed of product development, age and value of the installed capital base, leadership's technical competence and agility, nationally imposed inhibiting conditions by foreign adversaries, the availability of human and material resources, and reliance on the industrial base of the United States or United States allies and partners
3. a temporal evaluation of the competitive strengths and weaknesses of United States industry, including manufacturing surge capacity, versus the directed priorities and capabilities of foreign adversary governments
4. assessing any other issues that the Secretary determines appropriate.

Hundreds of studies exist on foreign DIBs, including dozens of studies on China's DIB. We discuss, review, and cite many of those studies in this report. However, there are key differences between those studies and the examination required by Sec. 1260C:

- This assessment is temporally repeatable. Many previous studies offer a snapshot in time that cannot be repeated for different circumstances in different eras.
- We provide an assessment and methodology that was designed to be applicable to any country. Many previous studies offer a snapshot of a single country's DIB or subset thereof, with methodologies that are not broadly applicable. Our assessment of China's DIB can be compared side by side with the same assessment for another country.
- We provide a methodology that was designed around the need for data from a distance. Some previous studies relied on in-country interviews or data provided directly from a country's manufacturing or scientific community, whereas this study relied on information that was publicly available.
- We assess the DIB as a whole and do not focus on particular sectors within the DIB (aviation, maritime, cyber, etc.).
- This study was designed to reveal the strengths and vulnerabilities of a DIB to understand the international dynamics that may affect the United States and its allies.

[4] Public Law 116-283, National Defense Authorization Act for Fiscal Year 2021, March 6, 2020, Section 1260C. The full text of Section 1260C is provided in Appendix A.

Our team made several assumptions based on the congressional mandate. First, we interpreted the objective to be an examination of the strengths and vulnerabilities *during peacetime*. As with the United States during World War II, an entire country's industrial base can be directed toward activities in support of war. We interpreted Sec. 1260C not as a study of China's entire industrial base but only its military-specific parts.

Second, this scoping decision affects dual-use capacities in the manufacturing sector, raw materials, workforce skills, and so on. We address these case by case in each section. In some areas, it made sense to include dual-use functions in our analysis (e.g., aircraft manufacturing). In other areas, the inclusion of a dual-use capability would have skewed the reasonable size and capacity of the DIB (e.g., including all information technology skills and workers in the potential "cyber" workforce).

Third, to assess China's strengths and vulnerabilities, we compare its progress against *its own goals*. This decision is based on the NDAA language. We examined what China's political leadership intends for its DIB and which strengths and vulnerabilities we can identify against its own explicit or implicit goals.

Fourth, any solution we created needed to be implementable without being overly taxing on government personnel. Congress designed this mandate to be repeatable in future years, with no expectation of a new office being created to execute this methodology. Therefore, we worked to provide a guiding protocol intended to be useful to a small team that is simultaneously working on other topics.

Approach for This Study

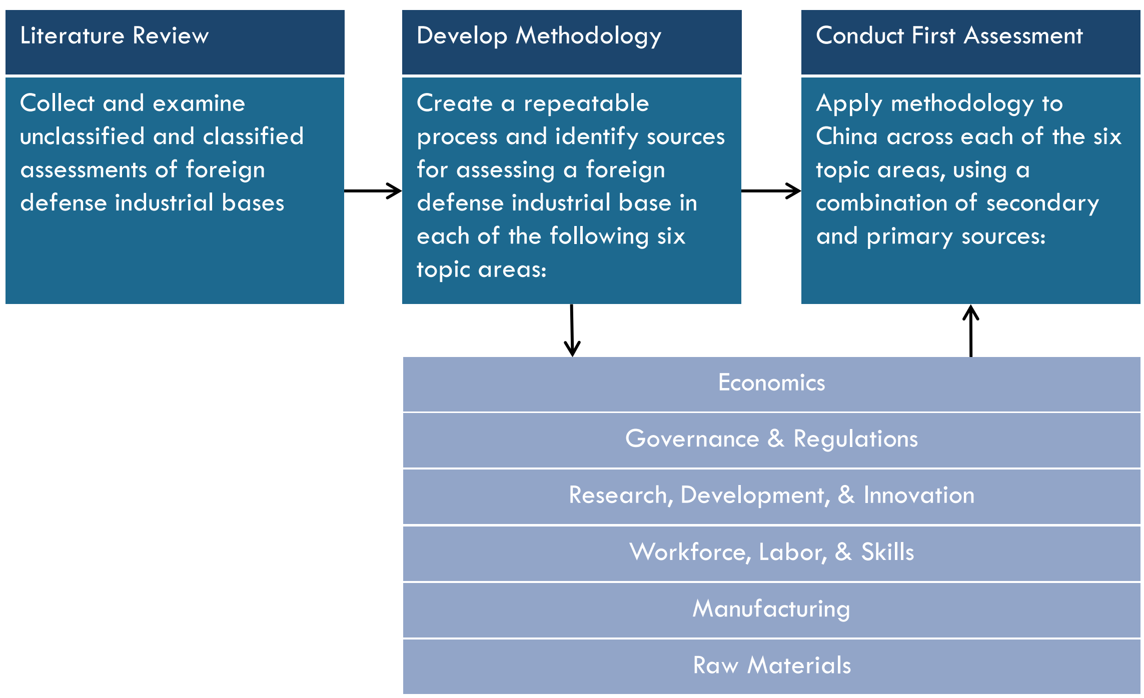
We began this study by framing and identifying relevant areas for assessment, beginning with the NDAA language and building from there. The six topics included in our methodology are economics; governance and regulations; research, development, and innovation; workforce, labor, and skills; manufacturing; and raw materials. These six topics were initially derived from the NDAA Section 1260C language (e.g., raw minerals, manufacturing), and we added topics (e.g., economics) based on previous studies of foreign DIBs.

We identified, collected, and examined studies (secondary sources) that had previously been conducted on foreign DIBs. We collected 148 such studies, and we rated 76 as being particularly relevant to goals set forth in the NDAA. We used these 76 studies to create a repeatable methodology that could be applied to any country. No single study fully met our goals for any of the six topic areas, so we chose the most useful aspects of each study's methodology to develop a method that was repeatable and country-agnostic for each of the six topic areas. We then identified sources that may be available for any country for each topic area. Some of the six topics were well suited to global data sources, while other topics were more reliant on country-specific literature. Similarly, some topics yielded a preponderance of quantitative assessments (e.g., labor, manufacturing, and raw materials), while others included aspects that required qualitative assessments (e.g., economics and governance) to fill out the picture.

Next, we applied the new methodology to China, as required by the NDAA. We then reviewed and refined the methodology based on that experience. When applying the methodology to China, we used both primary and secondary sources, which are cited throughout the report.

Figure 1.1 provides an overview of our approach. A detailed discussion of the methodology we used to conduct this study is provided in Appendix C.

Figure 1.1. Study Approach



Each of the six topics shown in Figure 1.1 is defined in Table 1.1, which also includes examples of subjects included in each section. We found these six topics to be interdependent. For example, the effectiveness, productivity, strengths, and vulnerabilities of a DIB's manufacturing base can be tied to the country's economics, to the raw material inputs available to factories, to the ability of the country's research and development (R&D) sector to create next-generation products, to the labor and skills of its workforce, and to the governance and regulations related to manufacturing.

Table 1.1. Six Topics for Assessing a DIB

Topic	Methodological Scope	Sample Subjects
Economics	Aspects of a national economy that affect DIB performance, capacity, and resilience; and economic aspects of a DIB that are key for understanding and recognizing its characteristics	• DIB structure and organization • Priorities • Financial system stability • Market and hierarchies
Governance and regulations	The set of laws, rules, and policies that create the environment in which the DIB operates	• Intellectual property protections • Acquisition processes • Import/export framework • Corruption
Research, development, and innovation	The domestic organizations, linkages, and contextual elements that participate in the military technological innovation process	• Measures of innovation potential • Incentive structures for new ideas
Workforce, labor, and skills	The labor pool from which DIB workers are drawn, the knowledge and capabilities possessed by those workers, and the country's ability to increase either the number of available workers or their capabilities and capacities	• Workforce capacity • Skills and education • Talent recruitment and retention
Manufacturing	Aspects of civilian and defense manufacturing that are solely dedicated to defense, those that are dual-use and can be applied to either, and those that are purely civilian but may be repurposed in wartime	• Output capacity • Production quality • Supply chain resilience
Raw materials	Metals and minerals used for a broad range of defense applications, including fuels, electronics, and automobile manufacturing	• Domestic resources versus reliance on exports • Stockpiles and reserves

In our assessment, we consider the Chinese government's own goals and its own assessment of China's vulnerabilities. There are many indicators that may suggest a country's areas of weakness. A country may import technology applications that it is unable, or chooses not, to manufacture domestically; it may create talent programs or education programs to address skill gaps in its workforce; and so on. These indicators, along with published strategy documents, military budget documents, and domestic think-tank analyses, provide insights into how a country perceives its own strategic needs and its own progress on or vulnerabilities in implementing its strategy. We include such self-assessed vulnerabilities in our analysis.

Throughout this study, we preferred secondary sources, because of time limitations. We used primary sources when secondary sources provided inadequate or outdated coverage of a specific topic. The secondary sources we began with included studies and assessments of foreign country DIBs, including China's, conducted by RAND, think tanks, universities, and others. The primary sources we used included Chinese national defense strategies, Chinese-authored self-assessments of the country's DIB, and other documents of relevance to add depth to our analysis and to fill in gaps left by secondary sources.

We strove to remove mirroring bias (the tendency to project the analyst's own context[5]) from our analysis. As an example, lack of market competition or insufficient separation between state leadership and the judiciary could be perceived as a weakness by American analysts, but we needed a method for analyzing China that would acknowledge its use of state-owned enterprises (SOEs) and Chinese Communist Party (CCP) control of the judiciary but at the same time not categorically list these as inherent weaknesses. We have allowed such differences to be accounted for, and we considered the potential that the arrangements could provide both strengths and weaknesses for the DIB.

Organization of This Study

This report is organized according to the six parts of our methodology: Economics (Chapter 2), Governance and Regulations (Chapter 3), Research, Development, and Innovation (Chapter 4), Workforce, Labor, and Skills (Chapter 5), Manufacturing (Chapter 6), Raw Materials (Chapter 7), and Conclusions (Chapter 8). The text of FY21 NDAA Section 1260 is provided in Appendix A, the methodology applied for each of these six parts is presented in Appendix B, and details about our approach to developing the new methodology are provided in Appendix C. Below, we provide context for China's DIB that crosses the six topics and provides a foundation to our analysis.

China and Its DIB

The PRC is a single-party state ruled by the CCP, and the People's Liberation Army (PLA) safeguards the CCP's role from domestic and international threats. The PLA's fundamental objective is to preserve the CCP's control over China. It has also been tasked by the CCP with winning high-tech wars along China's periphery (including wars against the United States) and building an expeditionary capability to protect Chinese people, property, and interests around the globe. The Chinese DIB has been a key player in building such a capability. Its efforts have also helped build the CCP's prestige through display of military equipment and exhibition of military capabilities, exporting influence along with military sales, and fulfilling employment promises to a select cadre and their subnational patronage networks.

These tasks are entrusted primarily to the Chinese DIB's eight major SOEs, massive conglomerates formed out of the government ministries that managed China's DIB in the old command economy.[6] Since several ministries were transformed into SOEs, some firms have been added and several have been consolidated, resulting in today's current group of firms,

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[5] Richards J. Heuer, *Psychology of Intelligence Analysis*, Langley, Va.: Central Intelligence Agency, Center for the Study of Intelligence, 1999, p. xxii.

[6] We include under the heading of SOE those firms that are owned by local authorities below the national governmental level.

which continue to dominate China's DIB. These eight are the Aviation Industry Corporation of China (AVIC), primarily responsible for aircraft; the China Aerospace Science and Technology Corporation (CASC) and the China Aerospace Science and Industry Corporation Limited (CASIC), responsible for aerospace and missile products; China South Industries Group Corporation (CSGC) and NORINCO,[7] which produce small arms and armored vehicles; China State Shipbuilding Corporation (CSSC), responsible for military ships; China National Nuclear Corporation (CNNC), responsible for the nation's nuclear industry; and the China Electronics Technology Group Corporation (CETC), which produces electronics.[8] In theory, these conglomerates are meant to function as normal corporations, competing to improve quality and reduce price in order to obtain new contracts, with at least some private shareholders and boards of directors to improve efficiency and enforce market discipline.[9] In practice, they still retain many of the characteristics of government ministries, especially in defense work. The head of each conglomerate is a government official of vice-ministerial rank, and their boards of directors tend to be controlled by CCP members.[10] The degree to which the company's CCP committee interferes in business decisions varies from company to company, but in central SOEs, such as those that dominate China's DIB, the party controls high-level personnel decisions and often reviews any decision that would involve major new projects, national defense, or national economic strategies before they are discussed by the board.[11] Xi has been working to regularize and increase the party's ability to influence or even direct firm decisionmaking in recent years.[12]

Thus far, the party has prioritized maintaining control at the expense of more economic and market-based decisionmaking, and although reform efforts have resulted in improved profitability, SOEs remain much less efficient and profitable than their private counterparts.[13] Government attempts to encourage competition by splitting many of the old defense production ministries into two conglomerates have likewise largely failed, as the SOEs have either recombined with their erstwhile competitors or specialized in different subsystems such that

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[7] NORINCO is the official abbreviation for this SOE, which is known as both China Ordnance Industries Group Corporation Limited and China North Industries Group Corporation Limited.

[8] Richard A. Bitzinger, "Reforming China's Defense Industry," in Richard A. Bitzinger and James Char, eds., *Reshaping the Chinese Military*, New York: Routledge, 2019; Tai Ming Cheung and Eric Hagt, *China's Efforts in Civil-Military Integration, Its Impact on the Development of China's Acquisition System, and Implications for the United States*, Monterey, Calif.: Naval Postgraduate School, Acquisition Research Program, 2020, p. 35.

[9] Bitzinger, 2019; Daniel Rosen, Wendy Leutert, and Shan Guo, *Missing Link: Corporate Governance in China's State Sector*, San Francisco, Calif.: Asia Society, in collaboration with Rhodium Group, 2018.

[10] Rosen, Leutert, and Guo, 2018, pp. 9–10, 15–16.

[11] Rosen, Leutert, and Guo, 2018, pp. 30–31; Kjeld Erik Brødsgaard, "China's Political Order Under Xi Jinping: Concepts and Perspectives," *China: An International Journal*, Vol. 16, No. 3, 2018, p. 8.

[12] Rosen, Leutert, and Guo, 2018, p. 24.

[13] Cheung and Hagt, 2020, pp. 15–16; Kenneth Boutin, "The Business of Defense: The People's Liberation Army and Defense-Industrial Development in China," in Richard A. Bitzinger and James Char, eds., *Reshaping the Chinese Military*, New York: Routledge, 2019, pp. 224–225.

there is often only one company capable of fulfilling a PLA contract.[14] When multiple companies are capable of executing a weapon program, contracts are often parceled up among all existing firms instead of a single award going to the most deserving firm.[15]

In addition to this lack of competition, the CCP has also proven unable to use contracts or courts to regulate DIB SOEs, though Xi's efforts to increase the use of formal legal channels of CCP control may lead to some improvement in this area. Traditionally, contracts between the PLA and DIB SOEs have been vague and largely unenforceable.[16] Both the PLA entities and the SOEs with which they interact are powerful entities within the Chinese government and CCP, and it is thus difficult for Chinese courts, which are themselves firmly under the party's political control, to referee between them.[17] As vice-ministerial level officials, major SOE executives outrank most local governments or the courts they manage in the party and state hierarchy.[18] Given the fact that the Chinese legislature, the National People's Congress, is also firmly under the control of the CCP, it is unlikely to provide any oversight independent of the party.[19] With negligible market competition and oversight outside of CCP organs, the party and PLA are forced to mostly rely on their direct administrative control over defense SOEs to monitor their performance and hold them accountable.[20] This can cause problems when neither the CCP nor the PLA devotes sufficient resources or expertise to watch SOEs.[21] That being said, the party's high degree of direct control over SOEs—both through its control over high-level personnel decisions and by issuing policies or strategies that SOE party committees must study and implement—can enable the party or army to circumvent market forces when those forces would cause companies to act contrary to PLA interests. This may be especially important, as most of the large state-owned conglomerates in the Chinese DIB make more money in their less regulated civilian divisions and have in the past complained of difficulty in making money with defense work.[22]

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[14] Cheung and Hagt, 2020, p. 21; Bitzinger, 2019.

[15] Bitzinger, 2019, pp. 212–214.

[16] Tai Ming Cheung, *Forging China's Military Might: A New Framework for Assessing Innovation*, Baltimore, Md.: Johns Hopkins University Press, 2014, p. 52; Susan M. Puska, Debra Geary, and Joe McReynolds, "Commissars of Weapons Production: The Chinese Military Representative System," in Cheung, 2014, p. 97.

[17] Congressional-Executive Commission on China, "Judicial Independence in the PRC," webpage, undated; Brødsgaard, 2018, p. 12.

[18] Rosen, Leutert, and Guo, 2018, p. 15; Brødsgaard, 2018, pp. 9, 12.

[19] Anthony Saich, *The National People's Congress: Functions and Membership*, Harvard Kennedy School, Ash Center for Democratic Governance and Innovation, 2015.

[20] Puska, Geary, and McReynolds, 2014, pp. 87–108; Cheung and Hagt, 2020, pp. 32–33; Brødsgaard, 2018, p. 9; Cheung, 2014, pp. 49–50.

[21] Puska, Geary, and McReynolds, 2014, pp. 87–108; Cheung and Hagt, 2020, pp. 32–33; Brødsgaard, 2018, p. 9; Cheung, 2014, pp. 49–50.

[22] Bitzinger, 2019, p. 214.

Private Chinese firms also engage in defense work, though they are much less prevalent than the state-backed conglomerates, especially as systems integrators.[23] Some, such as ZTE and Huawei, cooperate closely with the defense establishment.[24] Despite these breakthrough exceptions, private firms have historically struggled to break into the state-dominated, highly secretive, and organizationally and geographically scattered defense industry.[25] Recognizing the importance of securing access to cutting-edge technologies being developed or manufactured in the civilian sector, generations of Chinese leaders have called for "military-civil fusion" (MCF), or a greater integration of the military and civilian economies.[26] This dates to the 1949 foundation of the state, when China, perceiving itself surrounded by enemies, intended that consumer-goods producers would prepare to aid the DIB in wartime. Known originally as *civil-military integration*, both the priority and effective implementation of this aspiration lagged expectations.

Xi gave this project more attention than his predecessors with the 2015 raising of the newly coined MCF rubric to the level of a "national development strategy" and the creation of the Central Commission for Integrated Military and Civilian Development, which brings together military, government, and party leaders and which he personally chairs.[27] The vision of MCF is not only to benefit the DIB but that an integrated, mutually beneficial system of systems should emerge. Current efforts to facilitate the participation of private firms in the DIB include a variety of special development zones, expos attended by civilian producers and prospective military customers, and special contests in which civilian firms compete, and the winners are awarded government support.[28]

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[23] We include under the heading of privately owned enterprises (POEs) the several types that make up the category of foreign-invested enterprises.

[24] Bitzinger, 2019, p. 205.

[25] Cheung and Hagt, 2020, pp. 13–14.

[26] Cheung and Hagt, 2020, pp. 13–14.

[27] Cheung and Hagt, 2020.

[28] Previous research on MCF has identified three types of MCF zones: National Self-Initiated Innovation Demonstration Zones (国家自主创新示范区), National High-Tech Industry Development Zones (国家高新技术产业开发区), and National Military-Civil Fusion Innovation Demonstration Zones (国家军民融合创新示范区). For more details, see Alex Stone and Peter Wood, *China's Military-Civil Fusion Strategy: A View from Chinese Strategists*, Montgomery, Ala.: Air University, China Aerospace Studies Institute, 2020, pp. 81–82.

2. Economics

In this chapter, we address aspects of China's economy that might affect DIB performance, capacity, and resilience, and economic aspects of a DIB that are key for understanding and recognizing its distinguishing characteristics.

Fundamental Endowments

China is the world's second-largest country, and we must count its population among its strengths. High labor participation rates lead to a vast workforce.[29] Yet, changing dependency ratios point to a potential vulnerability. The general decline in fertility throughout Asia has had strong resonance in China, exacerbated by the legacy of the One-Child Policy, and means that dependency ratios are growing as the population ages.[30] This will exacerbate the burden on working age cohorts in coming decades.[31] This potentially affects labor mobility, especially if care of dependents remains a family responsibility, and conceivably labor availability if the wage bargaining power of working-age citizens increases. A system originally structured for mass mobilization of relatively cheap labor must change or become constrained. With the modernization of the PLA, military personnel requirements have decreased, thus relieving one potential source of pressure.

China is the growing power in Asia, with no peer competitor on its immediate borders, but it has geopolitical vulnerabilities in at least two regards. The first is that its neighbors are alarmed by the rise in Chinese hard power.[32] China previously could focus on the United States as its main regional competitor, but its very success in doing so has dissipated that benefit. It therefore lacks natural allies (with the possible exception of Russia) that could offer a partial solution to its raw materials needs. Russia has provided technology and weapons and has the capacity for

[29] In 2019, before the COVID-19 pandemic, China's labor force participation rate was 68.2 percent, compared with 67.6 percent for East Asia and the Pacific, 62.6 percent for the United States, and 60.8 percent for the world (World Bank, World Development Indicators, online database, updated June 30, 2021, "Labor force participation rate, total [% of total population ages 15+] [modeled ILO estimate]," variable series code SL.TLF.CACT.ZS, data downloaded July 3, 2021).

[30] The gender implications of this legacy are discussed in Chapter 5, "Workforce, Labor, and Skills."

[31] In 2020, China's overall dependency rate was estimated at 42.1 percent, its youth dependency rate was 24.6 percent, and its elder dependency rate was 17.5 percent. These figures for the United States were 54.6 percent, 28.5 percent, and 26.0 percent. By 2040, these rates are projected to be 59.9 percent, 20.7 percent, and 39.2 percent, respectively, for China, and 63.3 percent, 28.0 percent, and 35.3 percent, respectively, for the United States (U.S. Census Bureau, International Data Base, online database, September 2020). This means that, even now and certainly by 2040, the pipeline of young people entering the labor force is proportionately smaller in China.

[32] James Stavridis, "China's Military Buildup Is Worry for Neighbors and Warning for US," *Nikkei Asia*, October 1, 2019.

actions that might offset decisions by the United States and its allies to confront China. The second geopolitical vulnerability is that at least some of the material and energy requirements of China need to be found far afield, in countries that may not align with China in times of international tension.[33]

Macroeconomic Factors

The growth of China's economy over the past four decades has been so rapid as to become a historic economic phenomenon. From 1980 through 2019, China's economy grew 9.4 percent annually in real value terms, by far the most rapid growth of any sizable economy and the second-fastest growth overall. By 2019, its gross domestic product (GDP) measured $14.3 trillion, second only to that of the United States, at $21.4 trillion.[34] This size is an overwhelming strength for China's DIB. With growth in size has come nearly as impressive a rise in level of development. Industrial sector output is now comparable to the economy share in other major world powers, while the service sector still lags—a partial consequence of an investment-led growth strategy.[35] But this development has been uneven, leaving serious vulnerabilities. Some sectors that are key for supporting economic activity in general have lagged, particularly the financial sector. Although price stability has been maintained, which is crucial for forward planning by both privately owned enterprises (POEs) and SOEs, these same firms, especially SOEs, have received loans of sometimes questionable soundness, to the extent that they might in aggregate prove to be a vulnerability on banks' balance sheets.[36] Absent external capital and widening the role of foreign financial service providers in China (which has heretofore been limited by government policy, though these limits are being gradually removed), one recourse to ensure continued financial stability might be to constrain credit terms in a manner that places constraints on performers in the DIB or involved in dual-use production. The CCP might step in as ultimate guarantor or even allocator of financial resources to priority sectors or firms, as it has informally in the past, but only at the price of inflicting costs on the larger economy and employment generation. The more that foreign capital becomes available, the greater the likelihood that this potential DIB vulnerability becomes ameliorated.

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[33] Jessica Yun, "'Wishful Thinking': Why China Needs Our [Australia's] Iron Ore for 'Many Years' to Come," *Yahoo Finance AU*, June 10, 2021.

[34] Growth rates are calculated for 134 countries with available data and are from World Bank, 2021. Growth rates use the variable "GDP (constant 2010 US$)," series code NY.GDP.MKTP.KD. Nominal GDP is "GDP (current US$)," series code NY.GDP.MKTP.CD.

[35] In 2019, the industry share (including construction) of China's economy was 38.6 percent, and the services share was 54.3 percent. For the United States, these figures were 18.2 percent and 77.3 percent, respectively (World Bank, 2021, variables "Industry [including construction], value added [% of GDP]," series code NV.IND.TOTL.ZS, and "Services, value added [% of GDP]," series code NV.SRV.TOTL.ZS).

[36] Gary Jefferson, "State-Owned Enterprise: Reform, Performance, and Prospects," in Weiping Wu and Mark Frazier, eds., *The Sage Handbook of Contemporary China*, Sage Publications, 2018.

The scale and growth of China's economy mean that military production, even at its prodigious recent pace, does not impose an undue economic burden, unlike in the former Soviet Union. In fact, the share of GDP spent on DIB procurement, along with other costs associated with the military buildup, has remained under 2 percent of GDP from 2003 through 2020 in the official defense budget.[37] Figure 2.1 illustrates China's GDP and defense budget. (The same data for the United States are also shown in Figure 2.1, although serious issues with defining and valuing defense spending and determining valid exchange rates make comparisons less straightforward than the figure shows.) Equipment purchases grew to 41 percent of the budget in 2016–2017, the most recent official breakdowns.[38] However, actual defense expenditures, including paramilitary and security services, direct outlays by the Central Military Commission (e.g., on military R&D), space activities, recruitment bonuses, and other items that would be included in other nations' defense budgets, would increase total outlays by 35–40 percent in recent years.[39] This would put the defense burden closer to 2.3–2.4 percent of GDP. Further, while China could once focus resources on modernization, the result is that it has now reached a level at which it faces the choice between investment in modernization on the one hand and force readiness and sustainment on the other—a choice that peer military powers have faced for some time.

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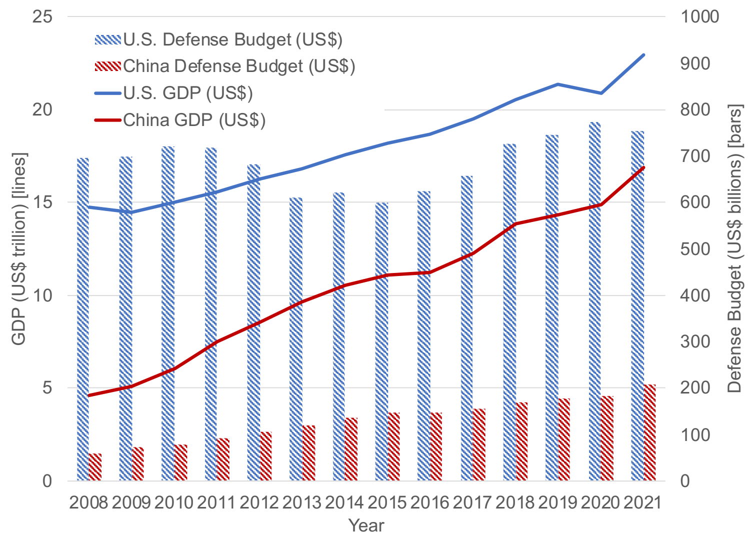
[37] Center for Strategic and International Studies, ChinaPower Project, "What Does China Really Spend on Its Military?" webpage, 2021b.

[38] Ministry of National Defense of the People's Republic of China, "China's National Defense in a New Era," July 24, 2019.

[39] Matthew P. Funaiole and Brian Hart, "Understanding China's 2021 Defense Budget," Center for Strategic and International Studies, March 5, 2021.

Figure 2.1. China and U.S. GDP and Defense Budgets, 2008–2021



SOURCE: Data from International Institute for Strategic Studies, Military Balance+ (online database), 2021, "China (PRC) and United States Defence Economics."
NOTE: Amounts are reported in current-year dollars using market exchange rates.

A principal strength for the DIB in a system such as China's is the ability of senior leadership to assign priority. Although China's system is not a pure command system in the classic sense, the unitary nature of CCP authority and its penetration to the level of the locality and the firm means that resources can be marshalled and allocated in times of constraint in a manner consistent with leadership preferences. Thus, China might be more capable of significantly increasing the defense spending share of its massive GDP (and attempting to reconcile the ensuing social and economic consequences) than might be the case elsewhere. But with that level of control comes risk. To the extent that the ability to assign priority is not tempered by informed debate among those holding alternative perspectives, one or both of two problems may arise: allocation of priority to areas that prove in reality to be less influential than had been intended and underfunding for those aspects of DIB production that come to be recognized as potentially more decisive than had been originally supposed.

This potential vulnerability within a system that might otherwise be viewed as a powerful tool for allocating to, and operating within, the DIB is accompanied by another arising from the same source. China's courts do not represent an independent branch of government but are, in essence, an instrument for CCP control.[40] This has historically raised a question about the enforceability of contracts and other agreements in a court of law should they be perceived as running contrary to senior leadership intent. This uncertainty could loom and affect risk-taking

[40] The relationship between the CCP and the judiciary is described in more detail in Chapter 3, "Governance and Regulations," in the section titled "Corruption."

behavior by POEs seeking to bring innovative products to market and thus serve as a damper on innovative activity in general and specifically in the realm of potential dual-use technology applications.

Microeconomic Factors

A DIB is a network linking industrial and service sectors and firms that collectively meet the needs of the military customer. Industrial organization in China is characterized by a mix of the classic Marxist SOEs and post-reform POEs. The latter are principally responsible for China's exceptional growth and development drive, but the SOEs remain and have, if anything, recently gained greater prominence in senior leadership's conception—not the least reason being the role they are intended to play in the DIB.[41] Eight SOEs form the DIB's backbone.[42] Some consist of up to several hundred subsidiary entities, plants, design and testing facilities, etc., and so play a major role not only in all stages of production but also in coordination, including with dual-use POEs and SOEs as assisted by CCP bodies.

China's DIB has been sufficiently able to achieve steady enhancement of both quantity and quality of deliveries to earn increased attention from U.S. armed services. The DIB has been designed to provide all needs of the PLA. However, as the enhanced quality comes closer to various technology frontiers, this intention falls short of capacity. Yet, China has become a major exporter of military components and systems. In 2017, the last year for which official data are available, China exported $4 billion in arms goods and services. This compares with $8.8 billion for Russia and $153.3 billion for the United States in the same year.[43]

The Center for Strategic and International Studies' (CSIS's) analysis of the Stockholm International Peace Research Institute's (SIPRI's) 2010–2020 data found China to be that decade's fifth-largest country in military exports.[44] Recent years show China to be second only to the United States.[45] CSIS's analysis indicates that China's exports go mostly to neighboring Asian countries (77.3 percent by value over ten years), followed by African countries (19.1 percent).[46] SIPRI reported that the top four Chinese defense firms had foreign weapon sales of

[41] Mercator Institute for China Studies, "Xi Signals Unshaken Commitment to State's Role in Chinese Economy," *MERICS Briefs/MERICS China Essentials*, August 27, 2020.

[42] In China, it is common to refer to the "Seven Brothers" of the defense industry, but the data require expanding beyond those few principal players. The eight SOEs are AVIC, CASC, CASIC, NORINCO, CSGC, CSSC/CSIC (recently combined), CNNC, and CETC.

[43] U.S. Department of State, *World Military Expenditures and Arms Transfers 2019*, 2019, Table IIe.

[44] CSIS, ChinaPower Project, "How Dominant Is China in the Global Arms Trade?" webpage, April 26, 2018. The Defense Intelligence Agency reached the same conclusion for a different time period using U.S. State Department data: "From 2012 to 2016, China's arms sales totaled about $20 billion, placing China among the world's top five global arms suppliers" (Defense Intelligence Agency, *China Military Power*, Washington, D.C., 2019, p. 107).

[45] Brett Forrest, "China Arms Industry Ranks Second Behind U.S.," *Wall Street Journal*, December 6, 2020.

[46] CSIS, ChinaPower Project, 2018.

$56.7 billion in 2019.[47] But gross numbers alone do not speak to the military value being transferred: Whereas aircraft and ships are expensive, for example, ever more capable drones are comparatively cheap. Table 2.1 shows China's arms exports across weapon categories using SIPRI data by trend-indicator value (TIV).[48] The data show an overall increase in 2018 and 2019, consistent with the decadal trend, but a falloff in 2020. This decline may reflect disruptions due to the global pandemic and the subsequent effects on production and acquisition budgets.

Table 2.1. Chinese Military Exports by Weapon Category (in millions of TIV)

Weapon Category	2018	2019	2020	Total
Aircraft	384	359	463	1,205
Air defense systems	127			127
Armored vehicles	207	271	136	614
Artillery	49	19	13	81
Missiles	310	159	74	543
Sensors	34	42	10	86
Ships	58	622	65	745
Total	1,169	1,472	760	3,401

SOURCE: SIPRI, SIPRI Arms Transfers Database, March 15, 2021a.
NOTES: All numbers are in millions. Blank values indicate less than 0.5 million. The definitions of these categories and the types of weapon systems included in each category are listed on the SIPRI website.

On the other hand, China is an importer of military goods on the technological leading edge. The most recent official data from 2017 show that China imported $1.1 billion in arms goods and services, an insignificant amount in terms of China's total trade.[49] But the ratio between arms exports and arms imports, 3.6, hints at some lags in China's ability to provide all PLA needs; the same ratio for the United States was 30.6, and for Russia, for which arms exports are a major factor in its trade balance, was 88. Looking at the same ratio for China, this time using the SIPRI TIV assessment, which ascribes the value of military resources transferred, system by system, rather than applying market financial valuations, we see that the exchange is near equal for 2017

[47] Forrest, 2020.

[48] SIPRI calculates the trend-indicator value (TIV) of each transfer based on the known production cost of each system and then aggregates these values to a total TIV in its reporting. This enables comparisons across weapon systems that may have a combination of known and unknown costs. TIV is not a currency value, nor is it a count of the number of items traded; rather it is a measure used to compare weapon sales that accounts for different currencies and for discounted costs of refurbished used weapons, older-generation versions of weapons, and newer, more advanced weapons. Thus, TIV represents the transfer of military resources rather than the strict financial value of the transfers (SIPRI, "SIPRI Arms Transfers Database—Methodology," 2021b, in the section "2. Explanation of the Tables").

[49] National Bureau of Statistics of the People's Republic of China, *China Statistical Yearbook*, 2019, "Table 11-2, Total Value of Imports and Exports of Goods."

and less than 1.2 over the period 2015–2019. (The same rate holds if the anomalous year 2020 is included).[50]

SIPRI data show military imports to China originating from six countries between 2018 and 2020, with 82 percent TIV value coming from Russia. Principal deliveries from both Russia and Ukraine were of aircraft and naval engines, with some missile sales.[51] Indeed, engines as a category represented the largest share of all 2015–2020 arms imports from all sources (3 billion TIV). This was followed by aircraft (2.3 billion TIV), air defense systems (565 million), missiles (527 million), and sensors (426 million).

Western nations have also been a source for advanced military components and systems for the PLA. France supplied arms totaling 345 million TIV over 2018–2020, again principally aircraft and naval engines, with rotary-wing aircraft as well. The United Kingdom (60 million TIV; aircraft engines) and Switzerland (33 million TIV; air defense and fire control radar systems) have also been major suppliers over the same years.[52] Table 2.2 shows these data; the decrease in sales in 2020 is consistent with the decline in global weapon sales during the COVID-19 pandemic.

Table 2.2. Chinese Military Imports by Country (in millions of TIV)

Country	2018	2019	2020	Total
Russia	1,696	1,108	600	3,404
France	121	126	98	345
Ukraine	78	78	78	234
United Kingdom	20	20	20	60
Germany	15	15	15	45
Switzerland	33			33
Total	1,962	1,347	811	4,120

SOURCE: SIPRI, 2021a.
NOTES: All numbers are in millions. Blank values indicate less than 0.5 million.

The figures cited only represent sales of weapons and the systems necessary to support, operate, and maintain them. In a pilot project, researchers at the Center for Advanced Defense Studies (C4ADS) examined all imports to and exports from China's DIB—rather than exclusively weapon systems—comprising "66,182 shipments [that] originated in China, bound

50 SIPRI, 2021a.

51 SIPRI, 2021a.

52 Over the longer period of 2015–2020, France supplied 844 million TIV, the United Kingdom 230 million, and Switzerland 195 million.

for foreign markets" and "65,727 shipments [that] were destined for China."[53] This expanded data set also includes parts and materials that do not reach SIPRI's threshold for inclusion. Unlike the SIPRI database, in which no transactions from the United States to China appear, C4ADS's analysis shows the United States to be the largest supplier to China's DIB, at almost 20 percent of all of China's DIB imports. C4ADS also found that eight of the top ten countries supplying China's DIB were U.S. allies and that some of the products being imported by China were listed on the European Union's list of export-controlled goods. Expanding the analysis to include goods that are not export-controlled but that could have potential dual-use applications revealed 40,157 shipments (61 percent of Chinese DIB imports). Within these shipments, C4ADS identified goods that could have aerospace and nuclear applications.[54]

Any nation's DIB is connected through value chains, with firms producing civilian goods and services not necessarily designed for the military customer.[55] In China, the SOEs forming the core of the DIB often have major lines of production for the civilian market that may dwarf their PLA deliveries of similar commodities (e.g., all forms of motor vehicles). But the lines of dependence go both ways, and although major military powers generally devote policy attention to the issue of ensuring deliveries of dual-use inputs, China has taken strong measures to draw civilian producers' attention to the concerns of the PLA.[56] Civilian firms, especially those in high-technology sectors, had always been encouraged to consider potential applications of value to the PLA. In the past half-decade, however, the concept of MCF has received considerable emphasis by the CCP and is being carried forward via several initiatives.[57] The MCF focus is not military production but rather a whole-economy effort to galvanize qualitative upgrades to DIB output through technological innovation. In addition, the DIB is increasingly expected through MCF to mobilize for surge production and support during crisis and conflict.

If carried out as envisioned by the CCP, MCF could prove to be a considerable source of strength to the DIB, but not necessarily to the larger economy if innovators are deterred from

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[53] After first identifying 1,665 entities participating in, or linked to, China's DIB, researchers used publicly available information from procurement announcements, product listings, and supplier profiles on the main Chinese military procurement platform. The entities were also searched for on the trade data aggregator Panjiva and on Thompson Reuters EIKON, a financial intelligence repository. The results of the searches yielded the nature, number, and source of goods and types of investments that the PLA and the sample entities are procuring (Marcel Angliviel de la Beaumelle, Benjamin Spevack, and Devin Thorne, *Open Arms: Evaluating Global Exposure to China's Defense-Industrial Base*, Washington, D.C.: Center for Advanced Defense Studies, 2019, p. 7).

[54] de la Beaumelle, 2019, p. 40.

[55] This would also include goods produced by primarily civilian producers that may be supplied in versions intended only for input to the DIB or delivery to the military.

[56] It did not prove feasible from publicly available data to determine what portion of non-DIB production going to the DIB was accounted for by imported materials, components, or systems from civilian producers.

[57] U.S.-China Economic and Security Review Commission, *Emerging Technologies and Military-Civil Fusion: Artificial Intelligence, New Materials, and New Energy*, Report to Congress, 2019.

other opportunities for applying the same energies.[58] The CCP goal is a "spin on" from the civilian sector to the DIB that would be repaid later by a "spin off" from successful DIB innovations to civilian applications.[59] There are other concerns raised by campaign-style initiatives like MCF that would exacerbate existing micro-inefficiencies in the economy. Campaigns are not the best vehicles for making discriminating choices over proper allocations of resources at the margin; functionaries seek to achieve status with hierarchical superiors through the zeal of their efforts to implement their understanding of what leaders intend. As with the campaign to build technology parks and innovation clusters in the general economy, which led to flurries of activity but relatively little connectivity, there are indications that the drive for MCF has led to questions about potential exaggeration of the size of funds being devoted and the effectiveness of such initiatives in bringing about change.[60]

Resilience and Transformation

Capacity for change is difficult to assess. It is dependent on complex interactions among institutional features, personal incentives, networks of communication, and means for coordination. What China gains in direct CCP control from having a small number of large, horizontally and vertically (if only partially) integrated SOEs make up the bulk of its DIB it may lose in efficiency and agility owing to the well-publicized general problems of China's SOEs, such as less productivity than POEs and less responsiveness to external change.[61] For the same reasons, corruption in various categories (from bribery, theft, and extortion to grayer areas, such as preferential allocation of resources and support for those in close personal relationships) may be more prevalent in this sphere. But as with any DIB, senior leadership is most likely willing, even in peacetime, to trade less efficiency for enhanced effectiveness on a selective basis for high-priority programs. The ability to assign such priority is a strength of the system.

The balance of incentives may determine whether effectiveness would be achieved. The intention to make the DIB sufficient for all PLA needs, combined with an increased wariness on the part of potential foreign arms exporters due to changing geopolitical perceptions, means that the primary customer for output from the DIB SOEs has few alternatives. Specialization means that most DIB contracts are single source to SOEs, with little interest in cultivating smaller firms that could become rivals. This would reduce SOEs' incentives to undertake risky innovative activity absent countervailing CCP intervention. To strengthen their economic foundation, gain

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[58] Emily Weinstein, "Don't Underestimate China's Military-Civil Fusion Efforts," *Foreign Policy*, February 5, 2021.

[59] Weinstein, 2021.

[60] Elsa B. Kania and Lorand Laskai, *Myths and Realities of China's Military-Civil Fusion Strategy*, Washington, D.C.: Center for a New American Security, 2021.

[61] Yuyu Chen, Mitsuru Igamia, Masayuki Sawada, and Mo Xiao, "Privatization and Productivity in China," *RAND Journal of Economics*, forthcoming.

experience satisfying different customers, or enhance contact with foreign sources of skill and intellectual property (IP), many DIB SOEs are involved in substantial and profitable production for the civilian sector. A not implausible incentive, therefore, could be to produce sufficiently to keep senior leadership and the PLA satisfied while emphasizing civilian production. One question with MCF is whether SOE managers might learn new behaviors when collaborating with managers trained in the POE environment or, instead, the POEs might adapt to practices in the SOE-dominated DIB and so become less adept in the very skills MCF seeks to transfer to the DIB.

Residual Leninist notions of the DIB being a crucial "commanding height" of state effectiveness and CCP control (and therefore the overwhelming reliance on SOEs) mean that there is an innate resistance to reform.[62] This highlights a final topic of potential strength or vulnerability, the issue of coordination within the DIB.[63] The great strides China's DIB has made in the decades since the Four Modernizations of agriculture, industry, science and technology (S&T), and defense began (first proposed in the Maoist era but implemented starting with Deng Xiaoping) should not be dismissed: The speed and quality of upgrades have made the PLA a modern fighting force.[64] But the dominance of the DIB SOEs means that more of the former system of command has persisted in the DIB. These siloed and highly fragmented entities have been able to cover considerable distance in recent decades, but the question remains of how well the DIB-CCP-PLA nexus will operate in determining priority, allocating resources, and mastering the levels of DIB performance required as China's military draws closer to the technology frontier.

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[62] On the commanding heights concept, see Vladimir Ilich Lenin, "Notes for a Report 'Five Years of the Russian Revolution and the Prospects of the World Revolution' at the Fourth Congress of the Comintern," *VI Lenin Collected Works,* Vol. 36, 1922; see also Lewis Siegelbaum, "The New Economic Policy," in "Seventeen Moments in Soviet History: An On-Line Archive of Primary Sources," webpage, undated.

[63] It did not prove feasible from publicly available data to determine the level of skills mobility within China's DIB and between it and the wider economy. There are indications that young people seek employment in SOEs because of the stability it affords.

[64] For the Four Modernizations, see, for example, Immanuel C. Y. Hsü, *China Without Mao: The Search for a New Order*, Oxford: Oxford University Press, 1990, Chapter 4, "The Four Modernizations."

3. Governance and Regulations

We define *governance and regulations* as the set of laws, rules, and policies that create the environment in which the DIB operates, and we examine how governance and regulations affect China's DIB across seven topics: technology transfer and IP protections; imports; exports; defense spending; acquisition and procurement policies, processes, and oversight; corruption; and any overarching laws not covered in the previous sections.

Technology Transfer and Intellectual Property Protections

Research and analysis of technology transfer in China focuses either on U.S. and Western technologies that are transferred or stolen by China's PLA, SOEs, or other enterprises[65] or on technology transfer *within* China by examining the relationship between scientific institutions and the PLA or SOEs.[66] There has been extensive research about the scale of China's foreign technology transfer in the forms of IP theft,[67] the siphoning of U.S. scientific research,[68] and the role of Chinese defense universities in this ecosystem.[69]

For a technology to be developed for military use in China, it must be issued a military license, and licenses are only available to domestic Chinese entities.[70] This licensing system provides both strengths and vulnerabilities for the licensees and for the state. The licenses benefit companies by serving as a seal of quality for the company's consumers and indicating that "the company is in good standing with the party."[71] China uses private enterprises to conduct some DIB functions when the state wants to create distance in hopes that these companies will be more successful than an SOE would be in acquiring dual-use components from the United States or other markets.[72] The United States is one of the largest exporters of dual-use components to

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[65] Federal Bureau of Investigation, *Executive Summary—China: The Risk to Corporate America*, 2019.

[66] Mark Stokes, Gabriel Alvarado, Emily Weinstein, and Ian Easton, *China's Space and Counterspace Capabilities and Activities*, prepared for the U.S.-China Economic and Security Review Commission, March 30, 2020, p. 67.

[67] Federal Bureau of Investigation, 2019; William Evanina, "Threat Briefing by William Evanina, Director of the National Counterintelligence and Security Center," video, China Initiative Conference, held at the Center for International and Strategic Studies headquarters, Washington, D.C., February 6, 2020.

[68] U.S. Senate, Committee on Homeland Security and Governmental Affairs, Permanent Subcommittee on Investigations, *Threats to the U.S. Research Enterprise: China's Talent Recruitment Plans*, Washington, D.C., 2019.

[69] Alex Joske, *The China Defence Universities Tracker: Exploring the Military and Security Links of China's Universities*, Australian Strategic Policy Institute, Policy Brief/Report No. 23, November 25, 2019.

[70] de la Beaumelle, 2019, p. 28.

[71] de la Beaumelle, 2019, p. 29.

[72] de la Beaumelle, 2019, p. 56.

China, and in some technology areas, such as aviation, China continues to rely heavily on imported U.S. components that it cannot build domestically.[73]

China is actively reforming and strengthening its IP protections. In 2020, China's Supreme People's Court created the first legal definition of what constitutes a trade secret[74] and reduced the monetary threshold for which an infringement of trade secrets case can be brought forward.[75] That year, China enacted a "slate of intellectual property law reforms . . . which are the first significant intellectual property law changes in Chinese patent law since 2008."[76] These changes were made in addition to the establishment of 20 IP tribunals in January 2017 and the inauguration and establishment of the Intellectual Property Tribunal of the Supreme People's Court in January 2019, whose purpose is to hear appeals of civil and administrative IP cases from across China.[77] These changes went into effect in June 2021, so the practical effects of these new laws remain to be seen.

These reforms might not yet appease foreign companies investing in China (and their host governments). A government relations manager at the American Chamber of Commerce in Shanghai wrote:

> Since China's IP framework is intrinsically linked with the country's legal system, solving issues like trade secrets theft, online infringement and political influence and local protectionism via the courts would require a complete structural overhaul. Beijing undoubtedly knows this, which means pledges made in the phase one trade agreement with the United States were at best hollow promises designed to appease Washington.[78]

As long as the CCP controls the judiciary, any IP enforcement remains in the party's control.

Imports

In general, importation of any good or service does not necessarily denote incapacity for domestic production. Given CCP leadership intentions that the DIB become fully self-sufficient in supplying PLA needs, the importation of technologically complex military goods suggests that the military customer is not yet confident that the DIB has the capacity to fully provide its

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[73] de la Beaumelle, 2019, p. 56.

[74] Laney Zhang, "China: Supreme People's Court Issues Interpretation on Civil Enforcement of Trade Secrets," *Library of Congress Global Legal Monitor*, November 5, 2020a.

[75] Laney Zhang, "China: Judicial Interpretation on Trade Secret Crimes Issued," *Library of Congress Global Legal Monitor*, November 12, 2020b.

[76] Jack B. Hicks and Cory Schug, "China Announces Long-Awaited—and Significant—Updates to Intellectual Property Protections," *National Law Review*, December 17, 2020.

[77] Aaron Wininger, "China's 4th Intellectual Property Law Court May Be Arriving Soon," *National Law Review*, December 2, 2020.

[78] Daniel Rechtschaffen, "How China's Legal System Enables Intellectual Property Theft," *The Diplomat*, November 11, 2020.

requirements. Importation may also be an indicator that in several militarily critical technologies China is still in the stage of copying and seeking to master production of its own versions of designs from abroad. It appears that the PLA service branches have the final say as to whether a domestic replacement component is good enough and the DIB can start using it instead of imports. On the other hand, if the importation signal is interpreted in this way, it should be noted that the arms shopping list is narrow, and so China could be inferred to be self-sufficient in many other areas by this criterion.

According to SIPRI's data, half of all weapon imports to China are for engines, including engines for military aircraft, combat ships, and armored vehicles. Russia continues to reap financial and strategic partnership benefits from supplying these systems to China. Similarly, as of 2018 China was the largest consumer of semiconductors, with the capacity to manufacture just 15.3 percent of the domestic demand, relying on Korea-, Taiwan-, and U.S.-based manufacturers to satisfy the remaining need.[79] China is actively seeking to shift this paradigm, setting a goal to manufacture 80 percent of the domestic semiconductor demand according to its "Made in China 2025" industrial strategy, which was released in 2015.[80]

U.S. regulatory actions have constrained China's ability to access semiconductors designed or manufactured abroad and the equipment required for to manufacture them domestically. The U.S. Department of Commerce has added several Chinese manufacturers, end users, integrated circuit (IC) designers, and supercomputer developers (e.g., Fujian Jinhua Integrated Circuit and Huawei Technologies) to the Entity List, cutting off access to U.S. firms' IC designs, advanced semiconductors, and American-made manufacturing equipment.[81] Further, access to several U.S.-produced semiconductor technologies (e.g., field-programmable gate arrays, artificial intelligence application-specific ICs) by Chinese military end users is highly restricted.

However, strengthened export controls by the United States create incentives for China to improve its own domestic manufacturing capability. A recent study of China's space market found that for space, the "U.S. and other countries' export control regimes are viewed as, and could well be, an initial challenge that ultimately results in a positive outcome by forcing the development of indigenous supply chains as well as domestic markets."[82] Additionally, export

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[79] Seamus Grimes and Debin Du, "China's Emerging Role in the Global Semiconductor Value Chain," *Telecommunications Policy*, April 18, 2020.

[80] Congressional Research Service, *China's New Semiconductor Policies: Issues for Congress*, Washington, D.C., R46767, April 20, 2021.

[81] Saif M. Khan, "U.S. Semiconductor Exports to China: Current Policies and Trends," *CSET*, October 2020. The Entity List appears as part of U.S. Export Administration Regulations. Maintained by the U.S. Department of Commerce, Bureau of Industry and Security, the list consists of specific governments, persons, and entities, including private firms to which exports by U.S. citizens or entities are restricted for certain or all goods, depending on the individual case (U.S. Department of Commerce, Bureau of Industry and Security, "Entity List," webpage, 2020).

[82] Irina Liu, Evan Linck, Bhavya Lal, Keith W. Crane, Xueying Han, and Thomas J. Colvin, *Evaluation of China's Commercial Space Sector*, Washington, D.C.: Institute for Defense Analyses, September 2019, p. vii.

controls could threaten the financial viability of U.S. firms, particularly in the semiconductor sector.[83]

Exports

The government has long encouraged DIB firms to increase exports. With possible exceptions for very high-tech weapons, China has proven willing to sell relatively advanced military, and even nuclear, technology, including armed drones and nuclear capable ballistic missiles, and to teach customers how to produce such weapons themselves. Restricting weapon sales to restrict access to key technologies is a relatively new problem for the PLA. A long-discussed revised export control law has recently been introduced.[84] When the central government had reason to limit arms sales, it frequently struggled to monitor and control DIB companies.[85]

China's military exports provide an indication of China's closest partners and allies. Table 3.1 shows the top ten countries that received Chinese military exports over the past three years, and these countries represent China's foreign defense priorities. China's relationship with Pakistan, for example, is clearly visible in these figures and reinforced when examining China's Belt and Road Initiative (BRI) investments in Pakistan or China's partisan leaning in Pakistan's border disputes with India.[86]

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[83] Antonio Varas and Raj Varadarajan, *How Restrictions to Trade with China Could End US Leadership in Semiconductors*, Boston Consulting Group, March 2020.

[84] Huijie Shao, "China Enacted the Export Control Law," *Perkins Coie*, February 25, 2021.

[85] Anupam Srivastava, "China's Export Controls: Can Beijing's Actions Match Its Words?" *Arms Control Today*, Vol. 35, No. 9, November 2005.

[86] Daniel S. Markey, "Preparing for Heightened Tensions Between China and India," *Council on Foreign Relations*, April 19, 2021.

Table 3.1. Top Ten Recipients of Chinese Military Exports (in millions of TIV)

Country	2018	2019	2020	Total
Pakistan	436	416	543	1,396
Bangladesh	92	637	27	756
Thailand	52	97	9	158
Myanmar	94	47		141
Saudi Arabia	40	40	40	120
Uzbekistan	107			107
Qatar	88			88
Algeria	57	24	3	84
UAE	46	12	11	69
Sri Lanka	1	59		61

SOURCE: SIPRI, 2021a.
NOTES: All numbers are in millions. Blank values indicate less than 0.5 million.

RAND analysis of China's activities in the developing world identified "favorite" countries that China invests in with Russia and Pakistan as "most important" to China to support "a buffer strategy to maintain a stable zone with neutral or pro-China states that will deny access to outside powers and counter threats to China's domestic stability."[87]

International relationships such as these provide opportunities for China but also raise stakes. Were tensions between Pakistan and India to escalate into war, for example, China would be involved because of the arms it has sold to Pakistan along with its investments in the disputed border territories.[88] In 2021, Myanmar, fourth on the list in Table 3.1, had a military coup followed by many civilian deaths, with one headline terming China the "biggest loser."[89] Although the Chinese "don't want to have a troubled state on their border,"[90] China becomes part of the international narrative when it is perceived as either complicit in or indifferent to the humanitarian effects of its policies. This is one downside of China's emergence from its former quiet approach to exercising international influence through military export policy.

The export of military services, as opposed to goods, is harder to measure in size or assess in function or quality yet provides similar strengths and vulnerabilities as exports of military weapons. China's export of private military contractors (PMCs), which provide military services and military equipment to an end customer, is underresearched and lacks data; more is known

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[87] Andrew Scobell, Bonny Lin, Howard J. Shatz, Michael Johnson, Larry Hanauer, Michael S. Chase, Astrid Stuth Cevallos, Ivan W. Rasmussen, Arthur Chan, Aaron Strong, et al., *At the Dawn of Belt and Road: China in the Developing World*, Santa Monica, Calif.: RAND Corporation, RR-2273-A, 2018, p. 294.

[88] Markey, 2021.

[89] Timothy McLaughlin, "China Is the Myanmar Coup's 'Biggest Loser,'" *The Atlantic*, February 22, 2021.

[90] Michael Sullivan, "China's Relationship with Myanmar's Military: It's Complicated," *All Things Considered*, NPR, March 29, 2021.

about China's use of private security contractors (PSCs), which provide security to a fixed location or infrastructure. China—including its SOEs and other enterprises—uses PSCs staffed by former PLA personnel in its BRI projects.[91] About 3,200 Chinese employees of private security groups were based abroad in 2016.[92] Export of cyber services is a feature of many countries' DIBs, including China. China assisted Myanmar in establishing an internet firewall to block citizens from accessing the entire internet[93] and provided cyber services to North Korea.[94] PMCs and PSCs create exposure vulnerabilities along with other DIB exports, though the lack of transparency makes it more difficult to track and attribute activities.

Defense Spending

Perhaps the single greatest advantage of the Chinese DIB is its sheer scale. Over the past ten years, the revenues and assets of most large Chinese defense firms increased by over 150 percent—a slower rate than the economy as a whole but sufficiently rapid that they now rank among the likes of Raytheon, BAE, and Northrop-Grumman as some of the largest defense companies in the world, with defense revenues in the tens of billions of dollars.[95] Given the rapid rate of growth of China's security sector, it would be remarkable if its SOEs did not undergo a revolutionary improvement in technological capabilities and production capacity. This has enabled the Chinese DIB to build capabilities that rival those wielded by the United States.[96] Even as their capabilities have grown substantially, Chinese defense SOEs have struggled to increase profitability, surpass Western capabilities in key areas, or engage in higher-level innovation.[97]

One of the most important infusions of resources is China's defense procurement budget. The CCP has kept defense spending at between 1.5–2.5 percent of GDP, depending on which expenses are included,[98] enabling the defense budget to grow in nominal terms more than 10 percent annually for the past two decades.[99]

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[91] Charles Clover, "Chinese Private Security Companies Go Global," *Financial Times*, February 26, 2017.

[92] Clover, 2017.

[93] McLaughlin, 2021.

[94] "Senior U.S. Official Accuses China of Aiding North Korea Cyber Thefts," Reuters, October 22, 2020.

[95] Lucie Béraud-Sudreau and Meia Nouwens, "Weighing Giants: Taking Stock of the Expansion of China's Defence Industry," *Defence and Peace Economics*, Vol. 32, No. 2, February 2021, p. 157.

[96] Bitzinger, 2019, pp. 210–211.

[97] There have been exceptions, and the Chinese DIB has produced some systems that may be considered more radically innovative, as well as some that are as good as or better than their Western counterparts (Bitzinger, 2019; Cheung and Hagt, 2020).

[98] Janes, "China Defense Budget Overview," *Jane's Sentinel Security Assessment: China and Northeast Asia*, June 8, 2020.

[99] Bitzinger, 2019, p. 194.

The inferred policy of pegging the defense budget to GDP carries more significance in China than elsewhere. Unlike in most countries, for which annual GDP is an outcome, in China it is a planning target, with party and local officials working hard (if not necessarily efficiently from a longer-term perspective) to meet senior leadership's expectation. GDP growth is expected to slow over the next two decades, potentially cutting the growth rate (not the total amount) of China's defense budget in half.[100] Furthermore, as wages rise, PLA deployments multiply, and equipment ages, a smaller and smaller portion of that budget will be allocated to the DIB for new weapons or research. CCP support for defense spending is likely to remain strong, and there is unlikely to be a precipitous decline, but unless the CCP breaks with its long-time policy of pegging defense spending growth to GDP growth (which it may be under pressure to do as growth slows at the same time as great power competition intensifies), DIB funding from the PLA is likely to grow less steadily over the next few decades.

Although the overall level of the defense share has not changed, Xi has recently overhauled allocation among the services, at the expense of the ground forces and the now defunct General Armaments Department.[101] This will likely mean more money for the PLA Navy, Air Force, and Rocket Forces, giving them greater ability to pursue their own favored projects.

The procurement budget alone cannot account for the rise of the DIB. Its SOEs have raised private capital by creating publicly traded and privately owned subsidiaries. Although the government or government-controlled entities often maintain a controlling stake in these subsidiaries, the sale of minority shares generates capital.[102] DIB firms have also raised capital by issuing asset-backed securities.[103] Perhaps 33 percent of the approximately $638 billion in assets controlled by the Chinese defense industry have been securitized, so there is likely still ample room to raise funds from the private sector.[104] Private investors are often keen to invest in DIB SOEs because of the sustained support they get from the highest levels of the CCP, widely believed to constitute an implicit guarantee against collapse or default.[105]

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[100] According to the International Institute for Strategic Studies, from 2015 to 2019, the Chinese defense budget grew by about 8 percent per year. PricewaterhouseCooper estimates that Chinese GDP growth could slow to as little as 2.2 percent per year by 2031. Other estimates are more optimistic, with S&P Global Market Intelligence predicting growth between 3.7 and 5.4 percent through 2030. See PricewaterhouseCooper, *The World in 2050: The Long View: How Will the Global Economic Order Change by 2050?* February 2017; Emmanuel Louis Bacani, "S&P: China's GDP Growth to Average 4.6% Through 2030 in 'Inescapable' Slowdown," S&P Global Market Intelligence, August 29, 2019.

[101] The portion of China's GDP dedicated to defense may have spiked during the COVID-19 crisis. It remains to be seen whether it will return to pre-pandemic levels, though this seems likely given the consistency of the policy before the pandemic.

[102] Douglas J. Elliott and Kai Yan, *The Chinese Financial System: An Introduction and Overview*, Washington, D.C.: The Brookings Institution, July 2013, p. 4.

[103] Cheung and Hagt, 2020, p. 17.

[104] Cheung and Hagt, 2020, pp. 17–18.

[105] Elliott and Yan, 2013, pp. 2–3.

Chinese defense sector SOEs also benefit from government subsidies, finance, and other support. Some take the form of direct payments from the central government, though Beijing has been trying to reduce these.[106] The Chinese central and local governments can also provide SOEs or their subsidiaries tax breaks, free land, free utilities, and in some cases even free facilities to support SOE operations and entice SOEs to move.[107] Finally, government organizations can use their influence over national and local financial institutions to provide cheap financing for SOEs they wish to support, or even to pressure banks to renegotiate terms if the SOE or one of its subsidiaries finds itself in distress.[108] SOEs' political connections may themselves harm the overall economy as more profitable private firms are starved of finance.[109]

Defense sector SOEs also often avail themselves of "government guidance funds," set up by central and local governments and sometimes effective at achieving specific intended goals. These are special funds meant to use government money as seed or anchor capital to attract private sector investment, and they are directed into particular technologies or sectors according to national economic development strategies.[110] Many of the technologies targeted are dual-use products or areas of research relevant to DIB SOEs.[111] Many government guidance funds are in theory meant to support small or startup private enterprises, but SOEs are often able to use their political connections and reputation as a safe investment to attract these funds. Government guidance funds can be a highly inefficient means of allocating capital—many of them are managed by local governments pursuing parochial interests, many are poorly managed, and many never attract private investment as intended.[112] That being said, as of 2020, these funds managed as much as $500 billion, representing a major source of potential funding for DIB SOEs.[113]

Acquisition and Procurement Policies, Processes, and Oversight

The PLA's acquisition and procurement system is plagued by inefficiencies. Many of these stem from massive, balkanized state-owned monopolies that dominate the DIB.[114] These companies are infamous for their risk aversion, lack of innovation, and hierarchical

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[106] Cheung and Hagt, 2020, pp. 15–16.

[107] Raymond Zhang and Cao Li, "With Money and Waste, China Fights for Chip Independence," *Wall Street Journal*, December 24, 2020; Rosen, Leutert, and Guo, 2018.

[108] Elliott and Yan, 2013, p. 2.

[109] Elliott and Yan, 2013, p. 4.

[110] Cheung and Hagt, 2020, p. 19.

[111] Cheung and Hagt, 2020, p. 19.

[112] Cheung and Hagt, 2020, p. 20.

[113] Cheung and Hagt, 2020, p. 19.

[114] Bitzinger, 2019, p. 212; Cheung and Hagt, 2020, p. 21.

bureaucracies and are less profitable than similar private firms.[115] Beijing is taking steps to rationalize them, but they remain both organizationally and geographically scattered across the country in hundreds of factories, subsidiaries, and research institutes as a result of Mao's "third front" drive to move the nation's defense industry into the hinterland to prepare for nuclear war.[116] For example, Table 3.2 illustrates the development times for several recent high-profile weapon systems of importance to the PLA. To highlight the inefficiencies of the PLA's acquisition and procurement system, the table shows the long timelines necessary to produce these weapons, the foreign dependencies in their development, and the relatively small number of systems procured. It is important to note that these programs were all initiated around 2000, and it is unclear how China's progress in the past 20 years might affect these insights.

Table 3.2. Development Times of Selected Systems of Importance to the PLA

Metric	**J-20 Fighter** (F-22 equivalent)	***Luyang*-Class 052C/D Guided Missile Destroyer** (*Arleigh Burke*–class equivalent)	**J-15 Fighter** (F/A-18 equivalent)	**Y-20 Transport** (C-17 equivalent)
Preliminary research to Milestone A	9 years (1998–2007)	052C: 4–5 years (1997/8–2001)	2–3 years (2005–2007/8)	4 years (2003–2007)
Technology and engineering development to Milestone B	9–10 years (2007–2016/7); maiden flight 2011	052C: 7 years: initial 2 years (2001–2003) followed by another 5 years (2005–2010)	9–10 years (2007/8–2016); maiden flight 2009	9 years (2007–2016); maiden flight 2012
Field deployment	Service entry with the PLA Air Force was achieved in February 2018	052C: 2005 052D: 2014	Production aircraft seen in late 2013; 2020 production resumed	First aircraft accepted by PLA Air Force in 2016
Foreign inputs	Indigenous platforms, foreign engines. In 2021, PLA Air Force indicated it is now fitted with indigenous WS10C engines.	Indigenous platform and armaments but heavily influenced by Russian design and armaments (surface-to-air missiles)	Reverse-engineered version of Russian Su-33	Design and technology inputs from Ukraine and Russia, especially from IL-76
Number in service	18	052C: 6 052D: 17	22	13
Total acquisition period	18–19 years	052C: 11–12 years	11–13 years	13 years

SOURCES: RAND analysis of data from Janes, website, undated; and Tai Ming Cheung, "Critical Factors in Enabling Defense Innovation: A Systems Perspective," *SITC Research Briefs*, Series 10, No. 2018-2, May 2018a.

The contracting system also contributes to inefficiencies in acquisition. Contracts between the PLA and defense SOEs are generally vague and lacking in any clear enforcement

[115] Bitzinger, 2019, pp. 198–199; Cheung and Hagt, 2020, pp. 15–16.

[116] Bitzinger, 2019, pp. 197, 214; Cheung and Hagt, 2020.

mechanism.[117] This means that the PLA relies on direct administrative measures reminiscent of the pre-reform command economy. Factories that fail to fulfill contracts on time often evade serious consequences for their lapses.[118] The PLA has representative officers stationed in factories and research institutes throughout the DIB, though they often lack the technical skill for ensuring that equipment meets standards.[119] They can be manipulated by the organizations they oversee, as enterprises are responsible for paying the representatives' salaries, and the representatives often seek positions in the institutes or factories they spent their careers overseeing.[120]

Most contracts are built on a "cost-plus" model, which does not incentivize SOEs to keep costs down and so reduce profit.[121] The lack of independent judicial, legislative, or media oversight means the PLA and CCP are reliant on the party and military's powers to directly monitor, regulate, and control DIB cost or time overruns and quality deficiencies. The PLA and CCP retain many of these administrative tools but only devote a fraction of the resources and talent they once allocated to this task.[122] Moreover, the high rank of most SOE leaders (vice-ministerial for most defense SOEs) and substantial influence these organizations have within the CCP can make them difficult for lower-level officials to regulate.[123] But when substantial top-level attention is given to a particular high-priority project, the policy options to cut through red tape and directly mandate that SOEs devote considerable effort in that area has in the past resulted in prominent successes.[124] The increasing competitiveness of Chinese arms in international markets may indicate that moves to give the service branches more influence over the acquisitions process and increased CCP oversight are bearing fruit, though it is also possible that such improvements are the result of increased funding and accumulated experience rather than institutional reform.[125]

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[117] Cheung, 2014, p. 52.

[118] Puska, Geary, and McReynolds, 2014, p. 97.

[119] Puska, Geary, and McReynolds, 2014, pp. 87–108; Cheung and Hagt, 2020, pp. 32–33; Brødsgaard, 2018, p. 9.

[120] Puska, Geary, and McReynolds, 2014, pp. 87–108; Cheung and Hagt, 2020, pp. 32–33; Brødsgaard, 2018, p. 9.

[121] Tai Ming Cheung, *Strengths and Weaknesses of China Defense Industry and Acquisition System and Implications for the United States*, San Diego, Calif.: University of California, San Diego, School of Global Policy and Strategy, UCSD-AM-18-218, June 25, 2018b.

[122] Cheung, 2014, pp. 49–50.

[123] Cheung and Hagt, 2020, pp. 20–21, 26, 33–34; Brødsgaard, 2018, p. 9.

[124] Bitzinger, 2019, p. 210; Cheung, 2018b; Mark Stokes, "China's Evolving Space and Missile Industry: Seeking Innovation in Long-Range Precision Strike," in Tai Ming Cheung, ed., *Fortifying China: The Struggle to Build a Modern Defense Economy*, Ithaca, N.Y.: Cornell University Press, 2013, pp. 49–50; Tai Ming Cheung, *Strengths and Weaknesses of China Defense Industry and Acquisition System and Implications for the United States*, Monterey, Calif.: Naval Postgraduate School, March 2017, pp. 343–345.

[125] Michael Raska and Richard A. Bitzinger, "Strategic Contours of China's Arms Transfers," *Strategic Studies Quarterly*, Spring 2020.

Beijing seeks to supplement the DIB with technology, financing, and other resources from the private sector. Traditionally, defense and civil industries were separate, and private sector participation in defense industry was minimal.[126] There was some cooperation in shipbuilding, as co-location with civilian shipyards meant access to larger drydocks, heavier cranes, digitized welding, more advanced ship design, and other new technologies or techniques to benefit naval construction.[127] The DIB also benefited from the civilian electronics industry, cooperating with firms such as Huawei and ZTE to obtain screens, computers, and communications equipment.[128] Finally, the PLA has made ample use of the technologies and infrastructure provided by China's civilian communications and remote sensing satellites.[129] Despite these efforts, civilian firms continue to face difficulties in participating in defense work. Although government programs can help increase the exposure of PLA or DIB SOE customers to civilian firms, the two still face a cultural divide that may prove difficult to bridge.[130] National security and secrecy requirements may also be an impediment, as some private firms seek to guard their technologies.[131] Finally, geography can be an issue. Co-location of advanced civilian and naval shipyards was key to DIB sector success, but much of China's DIB is located far from dynamic coastal centers where the private sector has blossomed.[132]

Corruption

Corruption has been a much-discussed topic inside China—including by Xi—and outside. The Defense Intelligence Agency specifically called out this problem, saying that residual corruption could undercut "structural reforms to improve command and control, procedural reforms to improve civil-military integration, and oversight mechanisms to eliminate waste and inefficiencies that stem from longstanding corrupt practices within the logistics sector."[133]

Xi's anticorruption efforts were initially widely reported by Chinese state media, but details about specific cases serve as propaganda more than transparency. The country boasts "nearly 40,000 supposed criminal cells and corrupt companies busted, and more than 50,000 Communist Party and government officials punished for abetting them," but some accuse the CCP of "enabling officials across China to lock away entrepreneurs and other citizens whom they

[126] Cheung and Hagt, 2020, p. 13.
[127] Bitzinger, 2019, p. 205.
[128] Bitzinger, 2019, pp. 204–205.
[129] Bitzinger, 2019, p. 204.
[130] Cheung and Hagt, 2020, pp. 23–25.
[131] Bitzinger, 2019, p. 214.
[132] Cheung and Hagt, 2020, p. 39.
[133] Defense Intelligence Agency, 2019, p. 48.

perceive to have gained too much wealth or influence independent of the party."[134] Given lack of individual details and transparency, the result might be that the anticorruption activities *are* the corruption.

Some analysts are beginning to examine how a state promotes corruption internationally in pursuit of strategic goals. In 2020, former U.S. government officials and analysts wrote of the BRI: "China now fosters land and sea connectivity in a global system built to Chinese norms and standards of cooperation, financed by a network of Chinese-funded banks, and enabled by Chinese graft and bribery on an epic scale."[135] They describe how BRI uses bribery and graft to buy access to foreign infrastructure and debt.[136] In non-BRI countries, China uses other tactics, including examples of Chinese donors with ties to the PRC having funded and influenced political campaigns in Australia in exchange for counterintelligence information.[137]

Overarching Laws

In this section, we examine aspects of China's governance or regulations that might not fall into any of the previous topics but that are nonetheless pertinent to the functioning of the DIB. We found that the CCP and its governance mechanisms enable China to concentrate considerable money, talent, and other resources into the DIB generally and into key projects specifically, often with quite impressive results. While the CCP has a high degree of direct authority over the DIB, balancing its desire for control with the need for greater efficiency and transparency has proven somewhat elusive.

The Xi administration has all but abandoned the efforts of its predecessors to increase competition among SOEs and improve efficiency and innovation by subjecting them to market pressures.[138] The CCP's Central Discipline and Inspection Commission is authorized to send inspection teams out to enterprises to root out corruption or disobedience, but it is only one organization with limited bandwidth, and its local subordinates are often suborned by local SOE, party, or government officials.[139]

Xi is working to make local courts and other local agencies more responsible to their superiors in Beijing (as opposed to local party bosses), and this may help address the problem of corruption and gross incompetence, but it is unlikely to do much to inject new dynamism into a

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[134] Emily Feng, "How China's Massive Corruption Crackdown Snares Entrepreneurs Across the Country," NPR, March 4, 2021b.

[135] Philip Zelikow, Eric Edelman, Kristofer Harrison, and Celeste Ward Gventer, "The Rise of Strategic Corruption: How States Weaponize Graft," *Foreign Affairs*, July/August 2020.

[136] Scobell et al., 2018.

[137] Zelikow et al., 2020.

[138] Bitzinger, 2019, pp. 212–213; Zi Yang, "The Invisible Threat to China's Navy: Corruption," *The Diplomat*, May 19, 2020.

[139] Yang, 2020.

state sector often criticized for its bureaucratic inertia, lack of innovation, and risk aversion.[140] Such reforms do not touch on the monopolistic structure of the Chinese defense market or restructure incentives for SOEs to prove more efficient and agile. This continued focus on and even expansion of the state sector also has a tendency to monopolize finance, as well-connected SOEs, which are themselves powerful interest groups within the government, use their influence to swallow ever more resources from the largely state-controlled financial sector, even from funds meant to support smaller private enterprises.[141] Meanwhile, private firms, which tend to be more profitable and offer higher returns on investment, often struggle to obtain finance.[142]

Finally, as presently constituted, the Chinese DIB relies heavily on party and government organs to root out corruption and ensure efficiency. Given the influence within the CCP of the SOEs and officials that these organs are tasked with policing, they have historically failed to root out much corruption, as discussed in the section above. At present, it seems unlikely that SOEs will be subjected to any real competition in the defense industry. Efforts to encourage mixed ownership and securitization have given some DIB SOE subsidiaries minority shareholders, but the ability of those shareholders to influence corporate governance or pursue efficiency (as opposed to pursuing political objectives) is limited.[143]

[140] Brødsgaard, 2018, p. 12.

[141] Cheung and Hagt, 2020, pp. 18, 20–21.

[142] Rosen, Leutert, and Guo, 2018, p. 10; Elliott and Yan, 2013, p. 4.

[143] Elliott and Yan, 2013, p. 4.

4. Research, Development, and Innovation

We define *research, development, and innovation* as the national defense innovation system (NDIS), or the domestic organizations, linkages, and contextual elements (sometimes referred to as *institutions*) that participate in the military technological innovation process. This model draws on existing research in commercial and military technological innovation and is designed to be country- and data-agnostic. Our analysis reveals that China's NDIS is strong, and it also reveals several vulnerabilities.

China's Research Capacity and Enterprise NDIS Participation Are High

China's overall research capacity and enterprise participation in defense technology innovation are high. In 2020, China published 566,914 scientific publications, compared with 597,385 for the United States. These totals put the United States and China as the most and the second-most productive countries in the world in terms of scientific research output. Table 4.1 depicts the annual number of scientific journal articles on which an organization located in the focal country is listed as an author's affiliation over the period 2016–2020. The United States has led China in each of most recent five years, but the gap has decreased each year.

Table 4.1. Scientific Publication, China and United States, 2016–2020

	2016	2017	2018	2019	2020
United States	537,258	555,632	575,238	596,824	597,385
China	324,964	361,526	418,422	513,129	566,914

SOURCE: RAND analysis of Web of Science data (Web of Science, citation database, Clarivate, undated).

China's high scientific research capacity is also evidenced by its global leadership in producing high-impact publications. In 2020, China published 8,650 high-impact scientific publications (publications in the global top 0.1 percent in terms of citations received). In the same year, authors affiliated with research organizations in the United States published 6,431 high-impact publications. Table 4.2 depicts the annual number of high-impact publications produced by each country over the 2016–2020 period.

Table 4.2. High-Impact Scientific Publication, China and United States, 2016–2020

	2016	2017	2018	2019	2020
United States	8,166	7,995	7,633	7,536	6,431
China	4,755	6,061	7,328	9,126	8,650

SOURCE: RAND analysis of Web of Science data.

Enterprise participation in China's military technology innovation process is high. In 2019 (the most recent year for which full patent data were available), China hosted 39 organizations that were granted at least five military patents in that year. Although not all military technology is patented (e.g., firms may wish to protect their IP via trade secrets or the patent may be classified), military patent data have been shown to conform to common definitions of military technology innovation.[144] Table 4.3 displays the number of domestic organizations in the United States and China that were granted at least five military patents during the year. The table indicates that in recent years, China has hosted substantially more organizations involved in patented military technology development than the United States.[145]

Table 4.3. Military Patenting Organizations, China and United States, 2016–2019

	2016	2017	2018	2019
United States	29	21	20	12
China	35	40	42	39

SOURCE: RAND analysis of Web of Science: Derwent Innovation Index data.

Table 4.4 displays the top ten Chinese military patenting organizations for 2019. The table indicates that China has significant organization-type diversity in the military technology development process. That is, sizable contributions are being made by universities, government research institutes (GRIs), and firms. In the United States, all ten of the top ten assignees for 2019 were firms.[146] Different organization types have been shown to specialize in distinct phases of the process of innovation. For example, patents that are developed by government agencies and universities have been shown to have broader (i.e., they are cited by a wider range of technical fields) subsequent technological impact than patents awarded to firms.[147] Further, university research has been shown to be more basic than corporate research.[148] China's high organization-type diversity in its military technology innovation process may produce technology that spans a broader range of the basic-to-applied spectrum and is of broader subsequent technological impact.

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[144] Web of Science: Derwent Innovation Index. See Chapter 2 for a description of the data collection process.

[145] See, for example, Jon Schmid, *The Determinants of Military Technology Innovation and Diffusion*, dissertation, Georgia Institute of Technology, 2018. At the end of FY 2020, the U.S. government kept a total of roughly 6,000 patents classified (Steven Aftergood, "Invention Secrecy," Federation of American Scientists, webpage, undated).

[146] In descending order of military patents granted in 2019, the top ten U.S. assignees are Raytheon, Axon Enterprise, Boeing, Cubic Corp, Hamilton Sundstrand Corp, Dana Heavy Vehicle Systems Group, Rockwell Collins, Omnitek Partners, Sheltered Wings, and Wilcox Ind Corp.

[147] Jon Schmid and Ayodeji Fajebe, "Variation in Patent Impact by Organization Type: An Investigation of Government, University, and Corporate Patents," *Science and Public Policy*, Vol. 46, No. 4, 2019.

[148] Manuel Trajtenberg, Rebecca Henderson, and Adam Jaffe, "University Versus Corporate Patents: A Window on the Basicness of Invention," *Economics of Innovation and New Technology*, Vol. 5, No. 1, January 1997.

Table 4.4. Top Ten Chinese Military Patenting Organizations, 2019

Patent Assignee	Military Patents, 2019	Organization Type
Nanjing University of Science and Technology	38	University
China Academy of Launch Vehicle Technology (CALT)	37	SOE
Hongdu Aviation Industry Group	31	Firm
Academy of Military Medical Sciences (No. 60 Res. Inst.)	30	GRI
Hubei Sanjiang Aerospace Honglin Exploration Control Co.	28	Firm
Army Engineering University of PLA	27	University
Junpeng Special Equip Co.	25	Firm
Beijing Institute of Technology	22	University
Xi'an Modern Chemistry Research Institute	21	GRI
Chongqing Changan Industry Group	20	Firm

SOURCE: RAND analysis of Web of Science: Derwent Innovation Index data.

The Linkages Between Actors in China's NDIS Are Relatively Weak

Analysis of the linkages between China's NDIS actors suggests relatively weak inter-organization ties. In China, the linkage between research organizations and enterprises (R-E linkage) is weak relative to the United States, the linkage between research organizations and government S&T organizations (R-G linkage) is highly dependent on a single organization, and the E-G linkage has historically been weak but is likely to strengthen given several priority MCF initiatives aimed at increasing enterprise engagement in the NDIS. The remainder of this section elaborates on these observations.

In China, the strength of the R-E linkage is weak relative to that linkage in the United States. Within a healthy defense innovation system, research organizations rely on enterprises to inform the final stages of the development process through feedback from end users.[149] Enterprises rely on research organizations to supply new scientific ideas they then embody in their technologies. In China, this channel of information exchange is weak. In 2020, China had 1,946 university-firm co-authorships on scientific publications; during the same year the United States had 8,162.

R-G linkage in China is highly reliant on a single organization: the National Natural Science Foundation of China (NNSFC). In 2020, the NNSFC funding share was over 70 percent. The outsized role played by NNSFC results in a very high Herfindahl-Hirschman Index (HHI) (0.55) for research funding in China.[150] In the United States, research funding is less concentrated: The

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[149] John A. Alic, Lewis M. Branscomb, and Harvey Brooks, *Beyond Spinoff: Military and Commercial Technologies in a Changing World*, Harvard Business Press, 1992.

[150] To measure concentration of scientific funding, we calculated the Herfindahl–Hirschman Index (HHI) for funding sources, which is the sum of the squared funded publication shares for funding sources within a country's research funding system. Our methodology for calculating HHI for research funding is explained in Appendix B in section B.3.

United States' HHI for research funding is 0.10. The top research funding agency in the United States is the National Institutes of Health, which is listed on roughly 25 percent of the United States' 2020 scientific publications.

Historically, the E-G linkage in China's NDIS has been weak, but the CCP and PLA are taking policy action to improve enterprise engagement. Although China's private sector has become increasingly capable of producing world class technology, historically little of this capability made its way into China's military. It is precisely to remedy this and to leverage its private innovative capabilities more fully for military ends that the Chinese government initiated its MCF policies.[151]

Four sets of MCF initiatives are particularly relevant for strengthening the E-G linkage. China has established more than 100 MCF zones, often with supporting infrastructure, for the development and testing of dual-use technology.[152] MCF zones allow commercial organizations, such as Beidou, to test their systems against military specifications.[153] To increase information flow, China has been hosting MCF expositions. In addition to providing commercial vendors with information on military demand, these expositions provide commercial vendors with information on special credit programs and how to contract with the government.[154] Illustrative of China's efforts to this end is the MCF Development High-Tech Equipment Achievement Exhibition (军民融合发展高技术装备成果展览), which has been hosted annually beginning in 2015.[155] China also hosts MCF competitions to encourage new commercial entrants into the defense market and introduce novel approaches to solving military problems. The largest competition, "The China Military-Civilian Dual Use Technology Innovation Application Competition" (中国军民两用技术创新应用大), is modeled after the television show Shark Tank.[156] Finally, China encourages commercial entry into the defense market by producing and distributing an MCF catalog ("Catalogue of Military Measurement Civil-Military Integration

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151 Brian Lafferty, "Civil-Military Integrations and PLA Reforms," in Phillip Charles Saunders, ed., *Chairman Xi Remakes the PLA: Assessing Chinese Military Reforms*, National Defense University Press, 2019, p. 632.

152 "2018 Military and Civilian Integration Events" [2018军民融合大事盘点], *Network Information Military Civil Fusion* [网信军民融合], January 2019.

153 Liu Jing, "Military-Civilian Integration from a Training Fever to See the Way of Breaking the Cocoon of the Traditional Military Industry," *PLA Daily*, July 18, 2018.

154 "2018 Military and Civilian Integration Events," 2019.

155 Deng Meng [邓孟], Zou Weirong [邹维荣], and Han Fuye [韩阜业], "The 4th Military-Civilian Integration and Development of High-Tech Equipment Achievements Exhibition Attracted More Than 40,000 Visitors" [第四届军民融合发展高技术装备成果展览吸引4 万余人参观], Ministry of National Defense of the People's Republic of China, October 26, 2018.

156 "2018 Military and Civilian Integration Events," 2019.

Technical Specifications") that specifies the technical standards required to sell to the Chinese military.[157]

China's Legal Institutions Are Relatively Weak

The third finding revealed by populating the NDIS model with data is that China's domestic institutions remain weak relative to the United States. In 2020, China was ranked 49th in the world in terms of International Property Rights Index score, compared with the United States at 14th.[158] In 2019, China ranked in the 42.8th percentile on the Regulatory Quality sub-index of the World Bank's Worldwide Governance Indicators, compared with the United States at the 88.9th percentile.[159]

Many of the outputs of R&D (e.g., new knowledge or processes) are non-excludable. In the absence of property rights protection, investors will be unable to fully appropriate the financial returns to their R&D investments. An inability to realize these returns leads to investment below the socially optimum allocation.[160] Property rights, specifically IP rights, serve to compensate the actors that invest in R&D for the provision of non-excludable goods. Empirically, this logic has been shown to hold: Countries that provide strong property rights tend to be more innovative than those that do not.[161] In China, provinces with strong IP protections invest more in R&D than those with weak protections.[162] A 2018 survey of American business conducted by the American Chamber of Commerce in Shanghai found China's lack of strong IP protections to be the number one barrier to increasing companies' R&D investment in that country.[163]

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[157] Wang Baolong [王宝龙] and Zou Weirong [邹维荣], "The Military Development Department of the Military Commission Officially Issued the 'Catalogue of Military Measurement Civil-Military Integration Technical Specifications (V2.0)' to the Whole Army [军委装备发展部面向全军正式发布]《事计量军民融合技术规范目录(V2. 0)》], State Commission for National Defense Mobilization, news release, April 19, 2017.

[158] Property Rights Alliance, International Property Rights Index 2020, 2020.

[159] World Bank, "World Governance Indicators," webpage, undated.

[160] Kenneth J. Arrow, Economic Welfare and the Allocation of Resources for Invention," in National Bureau Committee for Economic Research and Committee on Economic Growth of the Social Science Research Council, eds., *The Rate and Direction of Inventive Activity: Economic and Social Factors*, Princeton, N.J.: Princeton University Press, 1962.

[161] Cassandra Mehlig Sweet and Dalibor Sacha Eterovic Maggio, "Do Stronger Intellectual Property Rights Increase Innovation?" *World Development*, Vol. 66, February 2015.

[162] James S. Ang, Yingmei Cheng, and Chaopeng Wu, "Does Enforcement of Intellectual Property Rights Matter in China? Evidence from Financing and Investment Choices in the High-Tech Industry," *Review of Economics and Statistics*, Vol. 96, No. 2, 2014.

[163] American Chamber of Commerce in Shanghai, *Chasing Innovation: R&D Barriers and Incentives in China*, April 2018.

China's NDIS Is Reliant on External Sources of Technology and Education

Assessment of China's NDIS reveals that China depends on international suppliers for education and IP. These dependencies make China's NDIS vulnerable to policy changes made outside China. If the United States or any other major supplier were to enact policy that effectively stopped the flow of these goods and services into China, China would likely experience an NDIS disruption.

In 2019, roughly 1 million Chinese students were studying abroad, and nearly 350,000 were in the United States.[164] From 2016 to 2019, the number of Chinese students studying abroad increased by 6 to 7 percent per year.[165] It is likely that COVID-19 has reduced the number of students abroad, but more current data are not available.

For many of its major weapon systems and components, the Chinese defense acquisition system relies on imported technology and reverse engineering of systems produced abroad rather than indigenous innovative capacity.[166] Major PLA Air Force platforms are the result of reverse engineering foreign aircraft attained through license assembly agreements or import.[167] This approach can accelerate weapon system development, but it makes China dependent on other countries for many of its major weapon systems and thus constitutes a vulnerability.[168]

China's NDIS Output Is High

Military technology patent output in China is high. Figure 4.1 displays the number of quality-adjusted military patents produced by organizations from China and the United States over the period 2015–2019. In 2019 (the most recent year for which the patent data are complete), Chinese organizations were granted 675 military patents. After adjusting for quality, China's total is 544.[169] In 2019, the U.S.-based organizations were granted 220 military patents, 369 after adjusting for quality.

China also has a positive military patenting trend. Over the five years depicted in Figure 4.1, China's quality-adjusted military patent output grew at an average annual rate of 16 percent. In contrast, the United States' average annual growth decreased by roughly 6 percent per year over the same period.

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164 United Nations Educational, Scientific and Cultural Organization (UNESCO), Institute for Statistics database, undated.

165 National Bureau of Statistics of the People's Republic of China, 2019, "21-10 Statistics on Postgraduates and Students Studying Abroad."

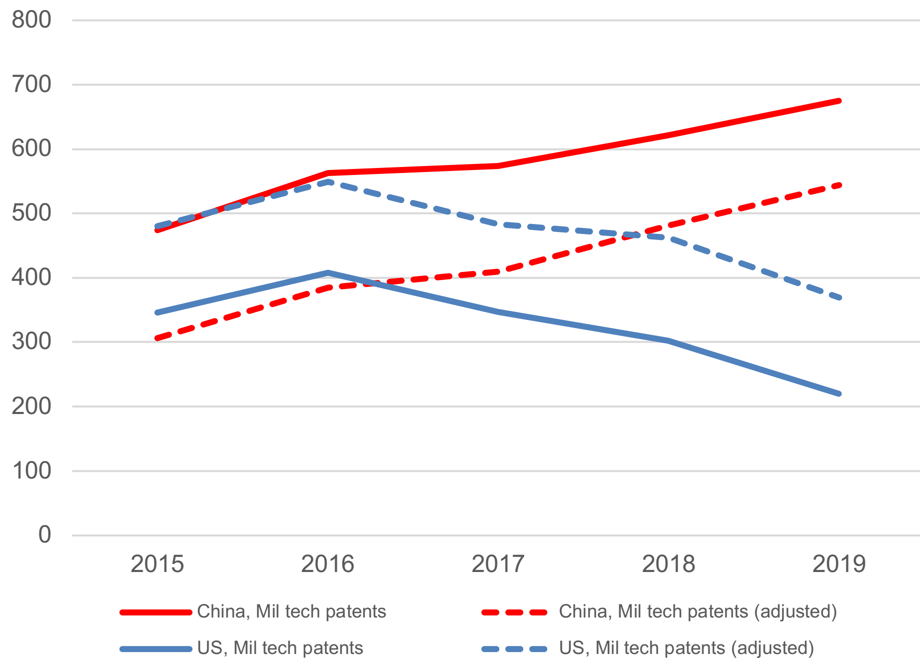
166 Cheung, 2018b.

167 Cheung, 2018b.

168 Cheung, 2018b.

169 RAND analysis of Web of Science: Derwent Innovation Index data.

Figure 4.1. Quality-Adjusted Military Patents, China and United States, 2015–2019



SOURCE: RAND analysis of Web of Science: Derwent Innovation Index data.

Table 4.5 depicts the frequency with which various terms appear in each country's military patents from 2016 through 2019. The table provides a high-level summary of the technology areas on which each country's military technologies are focused. For example, over the period, Chinese organizations were granted 300 military technology patents (12.4 percent of China's military patent total for the period) containing the term *missile* in either the patent abstract or the title. This suggests that a high proportion of China's innovative energy is directed at technologies related in some way to missile or countermissile technology.

Table 4.5. Military Patents by Technological Focus for China and United States, 2016–2019

Search Term	China	United States	U.S. Patent Gap (China Versus United States)
Missile	300	77	223
Laser	312	129	183
Infrared	187	51	136
Algorithm	190	66	124
Camera	170	69	101
Lens	143	50	93
Guidance	114	25	89
Sensor	321	241	80
Projectile	132	66	66
Electronic detonator	65	0	65
Rocket	102	38	64
Night-vision	60	4	56
Sighting telescope	58	2	56
Antenna	124	73	51
Laser emitter	36	0	36
UAS/UAV	96	71	25
Radar	71	46	25
Reconnaissance	30	9	21
Stealth/low observable	23	2	21
Warhead	30	16	14
Lithium battery	16	2	14
Ballistic	45	33	12
Electromagnetic gun	12	0	12
Inertial	37	27	10
Robot	42	37	5
Underwater	22	17	5
Laser range finder	8	4	4
Satellite	44	44	0
Image sensor	8	11	–3
Guided missile	7	10	–3
Submarine	11	15	–4
Wearable device	1	9	–8
Helicopter/vertical lift	18	37	–19
Autonomy	10	46	–36
Airplane/aircraft	107	265	–158

SOURCE: RAND analysis of Web of Science: Derwent Innovation Index data.
NOTES: UAS = unmanned aerial system; UAV = unmanned aerial vehicle.

5. Workforce, Labor, and Skills

In this chapter, we address the labor pool from which workers are drawn to China's DIB, the knowledge and capabilities possessed by those workers, and the ability of China to increase either the number of available workers or their capabilities and capacities.

The PRC has the largest workforce in the world as of 2019.[170] Yet official party statements and scholarly analyses indicate the existence of capability gaps that undermine the PRC's strategic objectives. China's science, technology, engineering, and math (STEM) workforce is insufficient in terms of quantity and quality to meet demand.[171] As a result, China's DIB is reliant on continued access to talent trained, and often working, abroad, and the Chinese government has instituted several initiatives to access this talent pool, including more than 200 talent recruitment programs and the establishment of research centers at foreign universities.[172]

The Ministry of Science and Technology has listed China's top priorities and areas of focus for strategic technologies and engineering projects, with the goal of achieving significant technological advances, as follows: core electronic devices, high-end chips, and basic software parts; large-scale IC manufacturing; next-generation broadband wireless mobile communications; high-end machine tools and manufacturing equipment; and other topics.[173] China's 2019 Defense White Paper[174] and 14th Five-Year Plan (FYP)[175] provide multiple national defense priorities regarding scientific and technological advancement: maritime interests; outer space, electromagnetic space, and cyberspace; aviation; and advanced weapon systems, including nuclear weapons. Our review of primary and secondary sources found insufficient data to determine the importance of biological or chemical weapon programs to the PRC's strategic priorities. The U.S. Department of State has consistently raised concerns over possible dual use of the PRC's growing biotech sector.[176]

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[170] World Bank, World Development Indicators, online database, updated June 30, 2021, "Labor force, total—China," accessed June 15, 2021.

[171] Tai Ming Cheung, Thomas Mahnken, Deborah Seligsohn, Kevin Pollpeter, Eric Anderson, and Fan Yang, *Planning for Innovation: Understanding China's Plans for Technological, Energy, Industrial, and Defense Development*, prepared for U.S.-China Economic and Security Review Commission, July 28, 2016.

[172] U.S. Senate, 2019.

[173] U.S. Senate, 2019, p. 18.

[174] State Council of the People's Republic of China, *China's National Defense in the New Era*, 2019, Sections III and IV.

[175] People's Republic of China, *14th Five-Year Plan*, Beijing, China: 5th Plenum of the 19th CPC Central Committee, March 2021, Section XIV.

[176] U.S. Department of State, *Executive Summary of Findings on Adherence to and Compliance with Arms Control, Nonproliferation, and Disarmament Agreements and Commitments*, Washington, D.C., April 2020.

China Plans to Address Its Vulnerabilities

To reduce workforce vulnerability, China has initiated policies to strengthen the domestic STEM workforce, often in connection with the DIB. A 2017 MCF document set forth plans to provide the civilian research sector with access to National Defense Patents and military research centers and recommended coordinating research efforts by establishing an information-sharing platform. Further plans called for the military and defense industries to increase their reliance on domestic higher education institutions and for the establishment of defense research and civilian research institutions, with specific talent recruitment plans for the defense industry.[177] Many other domestic-focused STEM talent programs have been implemented, although their connections to China's DIB may be indirect.[178] These efforts may shrink current gaps in the STEM workforce. These measures will not eliminate the gaps as they do not address, as will be discussed, either the coming demographic pinch or the vocational and higher education systems' failure to teach the skills that industry needs.

China's investments in talent programs are indicative of a self-realization that domestic talent shortfalls present significant security vulnerabilities. The United States and other nations are actively implementing regulations and reforms to cut off China's access to foreign STEM talent. Tools such as the China Defence Universities Tracker, produced and maintained by the Australian Strategic Policy Institute, can inform non-Chinese universities on how to assess risks of partnering with specific Chinese universities.[179]

The PRC 14th FYP offers a macro-level view of skill or labor weaknesses in the PRC workforce and expresses the desire to transform China into an S&T powerhouse (科技强国, Kējì Qiángguó).[180] The 14th FYP, published in March 2021, argues that for the PRC to meet this goal it must invest in artificial intelligence, quantum information, aerospace, deep earth, and deep-sea technology.[181]

While S&T have an element of manufacturing, the core resource is human ingenuity. The emphasis on specific fields indicates areas of priority that leadership has identified as S&T skill gaps it wants to correct.

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[177] U.S. Senate, 2019; Anastasya Lloyd-Damnjanovic and Alexander Bowe, *Overseas Chinese Students and Scholars in China's Drive for Innovation*, prepared for the U.S.-China Economic and Security Review Commission, October 7, 2020.

[178] Emily Weinstein, "Chinese Talent Program Tracker," webpage, undated.

[179] Joske, 2019.

[180] People's Republic of China, 2021, Sections II and III.

[181] People's Republic of China, 2021.

Higher Education's Focus on Publishing Leaves the DIB Dependent on Foreign-Trained Labor

The Chinese university system incentivizes professors to maximize publishing while ignoring education outcomes.[182] Without incentives to teach students more than the minimum, and no cost for passing students with only cursory testing, Chinese classes generally lack academic rigor.[183] A result is that university students' critical thinking skills generally decrease, and new knowledge is limited to what was on class tests.[184] A 2016 report notes that this has led to Chinese firms struggling to hire STEM talent in part because of a lack of domain knowledge or critical thinking skills.[185] China's DIB is thus reliant on the roughly 1 million college students studying abroad to fulfill critical S&T staff roles,[186] not all of whom are in STEM programs and some of whom do not return to China.

Younger Workers' Unmet Career Expectations Undermine Talent Retention

The Fudan and Tsinghua report found that a third of recent graduates, regardless of whether they were educated at home or abroad, quit their first job within six months of graduation because of unmet career expectations.[187] This indicates that the rising workforce, whether skilled or not, may be unsatisfied with PRC business practices that concentrate decisionmaking and rewards in the hands of a relatively small number of middle and upper managers. Admittedly, Chinese university graduates generally prefer to work for government entities or SOEs (most DIB firms are SOEs).[188] That said, China's SOEs have shown to be resistant to change, even changes directed by CCP leadership. This likely means that DIB firms may find it difficult to retain talent.

It is possible that the push for MCF, and possibly increased reliance on dual-use enterprises for defense production, might ameliorate this trend. If SOEs in the DIB to some degree come to emulate managerial and entrepreneurial practices found in China's POEs, the differential in desirability of employment conditions may be perceived as less acute. But such emulation may

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[182] Javier C. Hernandez, "Weighing the Strengths and Shortcomings of China's Education System," *New York Times*, August 2016b.

[183] Javier C. Hernandez, "Study Finds Chinese Students Excel in Critical Thinking. Until College," *New York Times*, July 31, 2016a.

[184] Hernandez, 2016b.

[185] Fudan University, Tsinghua University, and J.P. Morgan, *Skills Shortages in the Chinese Labor Market: Executive Summary*, October 2016, p. 11.

[186] Mini Gu, Rachel Michael, Claire Zheng, and Stefan Trines, *Education in China*, World Education News + Reviews, December 17, 2019.

[187] Fudan University, Tsinghua University, and J.P. Morgan, 2016, p. 13.

[188] Fudan University, Tsinghua University, and J.P. Morgan, 2016, p. 15.

come at the potential cost of increasing the incentive for DIB SOEs to focus even further on civilian sales to the neglect of the PLA customer. That is a trend that the CCP might well seek to mitigate. The other possibility is for POEs involved in MCF being brought more to heel to better accord with norms within the DIB. If so, the internal changes in corporate orientation might decrease the attractiveness of POEs as alternatives.

Low Funding and High Dropout Rates at Chinese Vocational Schools Leave Labor Unprepared for High-Tech Manufacturing

Welders, electricians, drafters, and other skilled laborers are essential for achieving national strategic interests. The 2016 skills gap report and 14th FYP note that the vocational workforce is not trained in modern manufacturing techniques or quality standards.[189] The PRC relies on a system of vocational high schools and colleges to train such labor. Yet these schools receive less than half the funding of traditional high schools and universities and have some of the highest dropout rates in the world.[190] This has left China's manufacturing, and therefore the DIB, workforce untrained for manufacturing cutting-edge products, such as aircraft engines. Nor can China's DIB rely on foreign trained workers, as the government provides no funding for overseas vocational training. Manufacturing automation may alleviate some of the current gap, though the degree to which the DIB will adopt additive manufacturing techniques remains unclear.

Demographics Are Not in China's Favor

If demographic trends continue, China will lack both sufficient personnel and certain critical skills for the DIB. By 2050, the proportion of Chinese citizens over the age of retirement is projected to be 39 percent of the population.[191] China does not have the infrastructure to support its aging population, so the state will have to either divert resources to build this capacity or allow the remaining working-age population to bear the burden of caring for large extended families. This will put additional financial burden on the already strained working population, and mass retirements will likely cause significant gaps in institutional knowledge, experience, and advanced skills in the DIB. Younger employees may enter the workforce with higher levels of education than their predecessors, but they will lack critical skills in project management, leadership, and institutional maneuver that come with experience. Altogether, this could stunt

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[189] Fudan University, Tsinghua University, and J.P. Morgan, 2016; People's Republic of China, 2021.

[190] National Bureau of Statistics of the People's Republic of China, 2019; Hongmei Yi, Linxiu Zhang, Yezhou Yao, Aiqin Wang, Yue Ma, Yaojiang Shi, James Chu, Prashant Loyalka, and Scott Rozelle, "Exploring the Dropout Rates and Causes of Dropout in Upper-Secondary Technical and Vocational Education and Training (TVET) Schools in China," *International Journal of Educational Development*, Vol. 42, May 2015, p. 119.

[191] CSIS, ChinaPower Project, *Does China Have an Aging Problem?* March 19, 2020.

China's economy, thereby thwarting its intent to sustain its rapid development.[192] Another effect might be to change the relative balance of power between workers and employers. China has had a history of labor unrest in recent decades that might become exacerbated as labor grows relatively scarcer. This creates a conundrum for the CCP as it seeks to balance between carrots and sticks in dealing with demographically determined shifts in relative power.

China's workforce is aging at a time when its fertility rate is below replacement levels and declining.[193] The Chinese economy, especially its powerhouse manufacturing sector, has historically relied on an abundant pool of young, affordable manual labor. However, sometime in the next decade China is projected to reach its Lewis Turning Point—the point at which sector profits begin to decrease because of the increased wages caused by labor shortages.[194] As a consequence, China may have to start importing foreign labor to sustain its profit margins,[195] or lose manufacturing jobs to countries with larger, cheaper labor pools, such as India.[196] Both scenarios are undesirable to China. Mass immigration of laborers will not be an easy shift for China, either practically or socially, in a country without immigration infrastructures and without a culture that values multi-ethnic diversity.[197]

China's lack of gender diversity in its workforce presents both a vulnerability and an opportunity. According to the World Economic Forum, China has some of the worst gender inequality in the world, ranking at 107 out of 156 countries in 2021 for overall gender equity (the United States, by comparison, is ranked at 30).[198] Moreover, China's gender gap is growing, not shrinking. Simultaneously, the state has cut child-care benefits, making it difficult for mothers to justify working unless they receive premium compensation.[199] This incentivizes women not only to stay home but also to have fewer children, both of which result in decreased human capital. This has already weakened China's workforce and constrained its economic growth.[200] As the Chinese labor pool continues to diminish and the proportion of elder dependents continues to grow, the detriment of excluding women from the workforce will become even more apparent.

To make up for labor shortages, China will have to enact policies that entice more women to join the workforce. This could be a potential area of human capital growth for China, but there

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192 Geopolitical Intelligence Services, *GIS Dossier: How Demography Shapes Geopolitics*, December 20, 2017.

193 Anthony Kuhn, "One County Provides Preview of China's Looming Aging Crisis," *All Things Considered*, NPR, January 14, 2015.

194 Mitali Das and Papa N'Diaye, "The End of Cheap Labor," *Finance & Development*, Vol. 50, No. 2, June 2013.

195 *The Economist*, "China's Achilles Heel," April 21, 2012.

196 *The Economist*, 2012.

197 *The Economist*, 2012.

198 World Economic Forum, *Global Gender Gap Report*, Geneva, Switzerland, March 2021, p. 10.

199 Eva (Yiwen) Zhang and Tianlei Huang, *Gender Discrimination at Work Is Dragging China's Growth*, Washington, D.C.: Peterson Institute for International Economics, June 16, 2020.

200 Zhang and Huang, 2020.

are several hurdles that may prevent its realization. The first is that reinstating child-care facilities and services will put a large burden on already constrained state resources. The second is that the CCP would have to embrace a hefty ideological flip, given that the feminist movement in China is an inherent threat to the state's patriarchal authoritarian nature.[201] It is therefore unclear whether the CCP will be both willing and able to enact the changes necessary to keep up with workforce demands.

Opportunities Exist for the PRC

While there are issues with available skills in China's workforce, there are also indicators of strength. Publicly available reports and indictments in the United States indicate that China's talent programs are providing the PRC with access to cutting-edge scientific innovations, but it remains unclear whether these programs will have a meaningful effect on the DIB's advancements. Additionally, China routinely targets foreign expertise to grow domestic capabilities. Chinese state-backed chipmakers have been offering above-market salaries to poach senior-level talent from semiconductor firms, particularly in Taiwan.[202] In part because of this talent recruitment program, as well as extensive state subsidies and IP theft, China's top chipmaker, Semiconductor Manufacturing International Corporation (SMIC), is now able to manufacture chips with 14 nm transistors—half a decade behind the state of the art.[203]

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[201] Leta Hong Fincher, "Feminism's 'Extraordinary Moment' in China Right Now, and Why the Government Sees It as a Threat," WBUR, October 8, 2018.

[202] Yimou Lee, "China Lures Chip Talent from Taiwan with Fat Salaries, Perks," Reuters, September 3, 2018.

[203] Saif M. Khan and Carrick Flynn, "Maintaining China's Dependence on Democracies for Advanced Computer Chips," Georgetown's Center for Security and Emerging Technology, April 2020.

6. Manufacturing

We examined manufacturing across civilian and defense uses to identify those aspects that are solely dedicated to defense, those that are dual use and can be applied to either, and those that are purely civilian during peacetime (though may be repurposed in wartime).

For over three decades, there has been much truth in the phrases that China is the "world's factory" or the "workshop of the world."[204] With its manufacturing accounting for roughly a quarter of the world's manufacturing output, China rose from insignificance in the 1990s to global manufacturing leadership by 2009.[205] China's success in developing leading manufacturing hubs in the Pearl River delta, greater Shanghai, and the Beijing-Tianjin-Hebei corridor has provided a solid manufacturing base for the development of a modern DIB. These commercial manufacturing hubs provided "breadth, efficiency and vertical integration of Chinese supply chains."[206] China's manufacturing DIB for the major warfare domains of land, air, sea, space, and cyberspace includes defense manufacturing capabilities that are "near world-class" and includes firms that "are comparable in quality to other international top-tier producers."[207]

China's manufacturing DIB is nested within a much larger manufacturing ecosystem. China's total manufacturing value added measured 3.9 trillion U.S. dollars (USD) in output in 2018 and accounted for around a quarter of China's economic output of $13.4 trillion.[208] Based on a 2018 United Nations (UN) estimate that relied on China's own self-reported survey data, Figure 6.1 shows the relative breakout between potential dual-use manufacturing and nondefense manufacturing by product categories.[209]

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[204] Heleen Mees, *The Chinese Birdcage: How China's Rise Almost Toppled the West*, New York: Palgrave Macmillan, 2016.

[205] Ian Colotla, Yvonne Zhou, John Wong, Jeff Walters, Justin Rose, and Lars Maecker, "China's Next Leap in Manufacturing," Boston Consulting Group, December 13, 2018, p. 3.

[206] Colotla et al., 2018, p. 6.

[207] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2020: Annual Report to Congress*, Washington, D.C.: U.S. Department of Defense, 2020, pp. 143–144.

[208] United Nations Industrial Development Organization, *Competitive Industrial Performance Index 2021: China*, 2020.

[209] These data are self-reported and derive from surveys and therefore may be subject to double counting and other discrepancies. If we assume that such inaccuracies are system-wide and not sector-specific, the relative sizes should be approximately correct.

Figure 6.1. Relative Economic Value Added by Manufacturing Codes for China, 2018

SOURCES: United Nations Industrial Development Organization, INDSTAT 2 2020 Database, ISIC Revision 3, undated; and United Nations, Department of Economic and Social Affairs, Statistics Division, *International Standard Industrial Classification of All Economic Activities (ISIC)*, Rev. 4, New York, 2008.
NOTE: The smallest slices of the chart are "other transport equipment" in dual use and "printing, recorded media" among the nondefense sectors.

By any measure, China's aggregate manufacturing base has been the largest in the world since 2009 and is presently considered the first or second-most competitive manufacturer across almost all International Standard Industrial Classification (ISIC) manufacturing categories.[210] At a minimum, the value added of each manufacturing category provides an indication of economic emphasis that currently favors metals manufacturing, computing machinery, chemical production, and vehicle manufacturing as lead elements of China's manufacturing sector.

Within China's massive manufacturing sector lies a manufacturing DIB composed of eight major SOEs that collectively include thousands of specialized and regionally affiliated

[210] United Nations Industrial Development Organization, 2020.

subsidiaries. The core SOEs have changed over time through mergers, reverse mergers, and spin-offs, but their composition and industry alignment are generally described as falling into six categories, listed and described in Table 6.1.[211]

Table 6.1. China's Major Defense Manufacturing Conglomerates

DIB Manufacturing Emphasis	Parent SOE	Manufacturing Activity
Land warfare, ground forces	• China North Industries Group Corporation (NORINCO) • China South Industries Group Corporation (CSGC)	Ground combat vehicles, main battle tanks, infantry fighting vehicles and soldier equipment, small arms and light weapons, ordnance
Air warfare, air forces	• Aviation Industry Corporation of China (AVIC)	Fixed-wing combat, transportation, bomber aircraft, rotary-wing aircraft
Naval warfare, sea forces	• China State Shipbuilding Corporation (CSSC) (the China Shipbuilding Industry Corporation [CSIC] was merged into the CSSC in 2019–2020)	Frigates, corvettes, destroyers, and cruisers; submarines (diesel and nuclear-powered); aircraft carriers; dock landing ships
Electronic warfare, electronic equipment	• China Electronics Technology Group Corporation (CETC)	Light unmanned aerial vehicles (UAVs), radars, computing resources, other military electronics
Space warfare, space forces	• China Aerospace Science and Technology Corporation (CASC) • China Aerospace Science and Industry Corporation Limited (CASIC)	Surface-to-air missile systems; intelligence, surveillance, and reconnaissance (ISR) systems; heavy UAVs, ballistic missiles, space launch vehicles
Nuclear warfare, nuclear facilities	• China National Nuclear Corporation (CNNC)	Nuclear reactors, nuclear weapons

SOURCE: Derived from Béraud-Sudreau and Nouwens, 2021.

These firms and their subsidiaries form the core of a DIB, comparable to those of the United States and Europe in defense manufacturing scale. Although China's defense SOE earnings are not always public information, one 2020 estimate of major defense firm rankings placed China's cohort of firms with a market capture (revenue) of 95 billion USD.[212] That is less than half of U.S. defense firms (277 billion USD), and substantially higher than Russian defense firms (12 billion USD).

Although these eight SOEs support China's DIB, their customer base is much more diverse than the military. For example, more than 75 percent of NORINCO's 2019 sales were not related to arms. In fact, in 2019, about 70 percent of all sales by these Chinese SOEs were not classified

[211] Béraud-Sudreau and Nouwens, 2021, p. 153. See Table 1.

[212] Defense News, "Top 100 for 2021," 2021. Rankings do not list totals for China National Nuclear Corporation (CNNC) and China General Nuclear Power Group (CGN).

as arms sales on average, compared with only 40 percent of sales for U.S. defense contractors and less than 10 percent of sales for Russia's two major defense companies.[213]

Vulnerabilities and Weaknesses

Reliance on foreign imports for certain high-technology manufactured goods remains a vulnerability of China's manufacturing sector. Trade deficits in manufacturing goods are not inherently a weakness of the PRC's manufacturing DIB, or for that matter the larger manufacturing sector. In some cases, China may simply have exceptional demand that cannot be satisfied solely by domestic production. A similar phenomenon can be found in the PRC's natural resource production, in which large domestic demand in categories such as petroleum and copper is only satisfied by importing the difference between that which can be domestically supplied and aggregate demand. However, sustained trade deficits in important manufacturing import categories do offer clues as to where manufacturing weakness may lie. Import data showing large trade deficits for particular manufactured items can point to areas where China's substantial manufacturing supply chains are unable to generate quality or volume of desired manufactured goods. The PRC imports in large numbers the manufacturing categories shown in Table 6.2, sometimes running deficits in these categories.

[213] CSIS, ChinaPower Project, "How Developed Is China's Arms Industry?" February 18, 2021a.

Table 6.2. Top PRC Manufacturing Import Reliance (as of 2019)

2019 Overall PRC Import Rank[a]	Manufacturing Import Category	Top Subcategories	2019 Import Value (USD)	Critical Suppliers[b]
1	Electrical machinery and equipment	• Integrated circuits • Cellular and wireless network equipment • Diodes, transistors, semiconductor parts	497 billion	Taiwan, South Korea, Vietnam
3	Machinery, mechanical appliances, nuclear reactors, boilers	• Computers, data processors, optical mechanical readers • Semiconductor fabrication tools and equipment • Motherboards, microprocessors	190 billion	Japan, Germany, South Korea
5	Optical, photographic, cinematographic, measuring	• Liquid crystal displays • Measurement and calibration instruments • Chemical analysis tools; polarimeters, refractometers	99 billion	Japan, Taiwan, USA
6	Vehicles other than railway	• Personal vehicles • Tractors, mass transportation vehicles • Chassis, engine cabs	75 billion	Germany, Japan, USA
11	Pharmaceuticals	• Medicine, therapeutic or prophylactic • Blood products • Sterile surgical materials; sutures, adhesives	33 billion	Germany, USA, Ireland

SOURCES: International Trade Centre, website, undated; United Nations, UN Comtrade Database, undated.
[a] Most other sizable import categories include natural resources derived from the extractive industries: petroleum, cement, minerals, and raw material for foodstuffs covered in other portions of this report. Manufactured metals, such as treated iron, steel beams, and copper wire, can be considered input materials for finished goods, or their own manufactured product depending on final use. When the value added for steel, iron, copper, etc. assembly is higher than the value of the material itself, these items are captured in their final goods category, such as vehicles, tractors, or electronics.
[b] Reimports from Hong Kong are excluded from this table and treated as PRC domestic manufacturing.

China's trade portfolio shows a reliance on international markets to satisfy domestic demand for high-technology components that are essential to a broader ecosystem of manufacturing. Integrated circuits (ICs)—both finished ICs and the components and tools used to build them—are key import items on which the PRC is increasingly dependent. Between the end of 2015 and 2019 (the last period for which reliable pre-COVID-19 data were available), China's import reliance grew for 28 of the top 30 "Electrical machinery and equipment" subcategories each grossing more than $1 billion.[214] This means that, despite committed efforts identified in China's

[214] For automated machine centers and some foundry equipment, the PRC reduced import levels during the 13th FYP, but for other IC categories—finished ICs (+34%), IC manufacturing tools (+88%), data processing machines (+18%), and IC parts and accessories (+46%)—foreign import reliance only grew during the period.

13th FYP to reduce foreign reliance on IC and machinery imports,[215] China's domestic ambitions lost ground to a combination of foreign cost competitiveness and surging global demand that grew faster than China's domestic IC industry could offset. IC trade deficits continue to remain a sore point in China's industrial policy, and China's attempts to develop a domestic IC capability comparable to Taiwan's through use of funding and talent acquisition is generally considered to have generated more failure than success.[216]

In terms of DIB-related manufacturing, China's annual spending on military equipment has grown in the past decade from $26.2 billion in 2010 to $63.5 billion in 2017.[217] The portion of resources devoted to military equipment has also grown; where a third of military spending went toward equipment in 2010, it grew to more than 40 percent by 2017. This is most evident in China's ship-building sector. China's navy has been launching new ships at such a rapid clip that it has been likened to "dropping dumplings into broth."[218] Similarly, China's aviation industry is also growing, but despite this growth and China's efforts to develop the capability domestically, China remains dependent on Russia, Ukraine, and, to some extent, France for aircraft engines. As mentioned previously, engines as a category represented the largest share of all Chinese arms imports between 2015 and 2020.

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[215] Katherine Koleski, *The 13th Five-Year Plan*, prepared for the U.S.-China Economic and Security Review Commission, February 14, 2017, pp. 9, 11.

[216] Emily Feng, "A Cautionary Tale for China's Ambitious Chipmakers," NPR, March 25, 2021a.

[217] CSIS, ChinaPower Project, 2021a.

[218] Andrew S. Erickson, ed., *Chinese Naval Shipbuilding: An Ambitious and Uncertain Course*, Annapolis, Md.: Naval Institute Press, 2016; Mike Yeo, "China's Military Capabilities Are Booming, but Does Its Defense Industry Mirror That Trend?" *DefenseNews*, August 14, 2018.

7. Raw Materials

We define *raw materials* as metals and minerals that are agriculture- and forestry-based and are used for a broad range of applications, including fuels, electronics, and automobile manufacturing. This assessment focuses on minerals for which there is economic value. For the purposes of this assessment, we are focused on raw materials associated with metals and minerals that can support a country's DIB.

China's approach to raw materials has historically been strategic. Using rare earth elements (REE) as a case study, China has employed various policy levers, such as R&D investment and export controls, to assume a dominant position in the global marketplace for a raw material that is essential to electronic devices and defense systems. Up until the mid-1980s, the United States accounted for the majority of REE production, but China overtook the United States in production because of its consistent investment in rare-earth-related refining and processing technologies.[219] In 1990, REE became a protected strategic sector in China, with a complete ban on foreign investment in rare earth mining. In the 2000s, China began to move up the REE value chain by increasing the number of export restrictions (e.g., quotas and tariffs), which provided a powerful incentive for manufacturers that rely on REE to relocate their production facilities to China.[220]

Nearly Half of Concentrated Minerals Are Concentrated in China

REE is only one of many raw materials on which China has focused its long-term planning. Overall, China is well positioned for access to raw materials. Of the 37 raw materials that are considered concentrated (as opposed to widespread) and relevant to defense applications, 18 are concentrated in China and another 14 are concentrated in countries with which China has strong diplomatic and economic relationships, such as Russia and BRI countries.

Figure 7.1 shows the defense-related raw materials that are considered concentrated and whose production is outside China. Light pink illustrates the countries that are part of the BRI. Only five materials are concentrated in the United States (dark blue) or its close allies Australia and Canada (light blue). Because these raw materials are primarily produced outside China, the Chinese DIB will be dependent on trade with these countries for access. China has already engaged in various efforts to ensure access to some of these minerals via diplomatic and

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[219] Carlos Aguiar de Medeiros and Nicholas M. Trebat, "Transforming Natural Resources into Industrial Advantage: The Case of China's Rare Earths Industry," *Brazilian Journal of Political Economy*, Vol. 37, No. 3, July–September 2017.

[220] Richard Silberglitt, James T. Bartis, Brian G. Chow, David L. An, and Kyle Brady, *Critical Materials: Present Danger to U.S. Manufacturing*, Santa Monica, Calif.: RAND Corporation, RR-133-NIC, 2013.

economic efforts with Brazil (shown in purple), South Africa, Congo, Chile, Estonia, Turkey, and Kazakhstan. For example, in 2011, a Chinese SOE acquired a 15 percent equity share of the private company that owns Brazil's largest niobium mine, producing 85 percent of the world's supply. (Niobium is primarily used as a steel hardener, but it is also used in high-temperature military applications, such as jet engines and missiles.) In 2016, another Chinese SOE acquired 100 percent of the second-largest Brazilian niobium mine, producing 8 percent of the world's supply.[221]

China and the United States May Need to Compete for Some Strategic Minerals

Among primary sources in which China discusses its need to stockpile critical raw materials, a 2020 report from the Chinese Academy of Natural Resource Economics analyzed resource reserves, production, consumption, and import and export trade flow based on the list of China's strategic minerals catalog from 2016 in comparison with the U.S. list published in 2018 and the European Union list from 2017.[222] The academy is subordinate to the ministry that released the 2015 *National Mineral Resources Plan*, implying that this report is a relatively authoritative interpretation. Figure 7.2 shows the minerals that China, the United States, and the European Union list as strategic in their official documents; this figure does not reflect scarcity.[223] The overlapping portions of the Venn diagram indicate which materials that China, the United States, and the European Union may compete over in the global marketplace.

Figure 7.2 also highlights that there are many materials China considers strategic—petroleum, iron, copper—that have not been included in this analysis, as they are readily available in the global marketplace and are not concentrated in a single country. Assured access is important, but presumably these materials will always be available for the right price.

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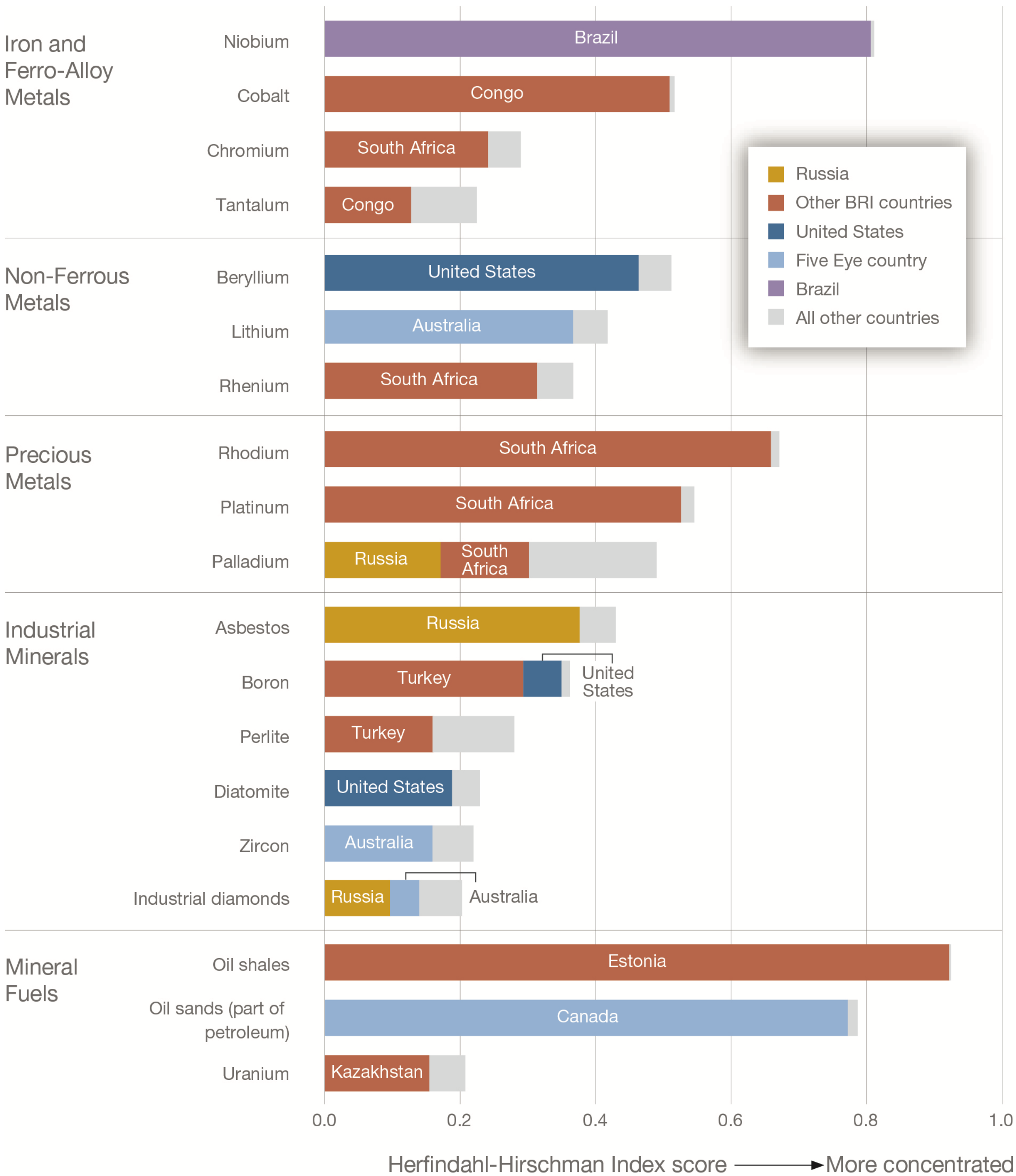
[221] Andrew L. Gulley, Nedal T. Nassar, and Sean Xun, "China, the United States, and Competition for Resources That Enable Emerging Technologies," *Proceedings of the National Academy of Sciences*, Vol. 115, No. 16, April 27, 2018a.

[222] Chen Jiabing [陈甲斌], Huo Wenmin [霍文敏], Feng Dandan [冯丹丹], Wang Qiang [王嫱], Yu Lianghui [余良晖], Liu Chao [刘超], Xu Yina [苏轶娜], Yin Lijuan [殷俐娟], Hu Dewen [胡德文], and Wen Shaobo [闻少博], *Analysis of Strategic (Critical) Mineral Resources Situation in China and the U.S. and the E.U.* [中国与美欧战略性（关键）矿产资源形势 分析], Beijing: Chinese Academy of Natural Resources Economics [中国自然资源经济研究院], 2020.

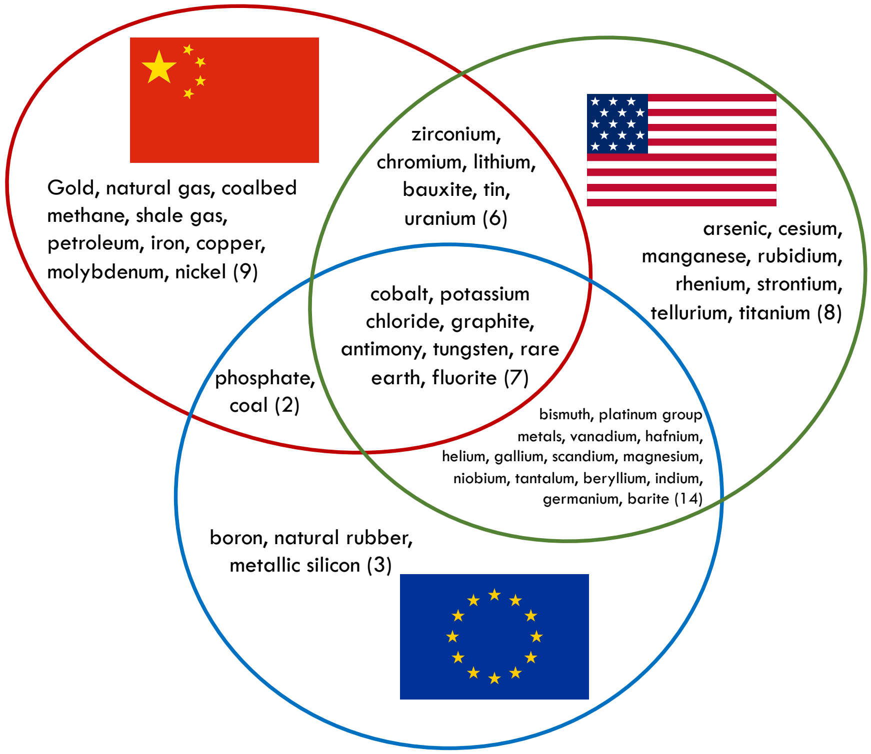
[223] Ministry of Natural Resources of the People's Republic of China, *The 2015 Ministry of Natural Resources Plan: National Mineral Resources Plan (2016–2020)* [*全国矿产资源规划（2016—2020年)*], Beijing, China, 2015.

Figure 7.1. Critical Defense-Related Raw Materials Concentrated Outside China



SOURCE: RAND analysis of *World Mining Data 2020*.

Figure 7.2. Strategically Important Minerals as Reported by China, the United States, and the European Union



SOURCE: Adapted from Chen et al., 2020.

The academy report recognizes that China, the European Union, and the United States lack sufficient domestic sources of oil, iron ore, manganese ore, chromium, copper, cobalt, lithium, and potassium chloride (potash) and that international competition for these minerals is likely to be fierce. This weakness is asymmetric, since China is more reliant on imports than either the European Union or the United States for those minerals. Chromium, cobalt, and lithium are notable because all three are concentrated in South Africa, Congo, and Australia, respectively. Petroleum, iron, manganese, and copper all have an HHI score of 0.10 or less, so although prices fluctuate, there are a variety of market producers. China, the European Union, and the United States similarly lack niobium, tantalum, and platinum group metals, which have concentrated productions in Brazil, Congo, and South Africa, respectively. In addition to the Chinese efforts to invest in the Brazilian niobium mines, a Chinese SOE and the China-Africa Development Fund took a 45 percent stake in Wesizwe Platinum Limited, a South African mining company focused on Platinum Group Metals, in 2010.[224]

[224] Simon Mundy, "China Enters South African Platinum Sector," *Financial Times*, December 17, 2010.

Although China Has a Robust Domestic Production, It Is Still Dependent on Other Countries

Combining the methodology with primary source documents leads to the insights about the strengths and vulnerabilities of China's raw materials for its DIB listed in Table 7.1.

Table 7.1. Chinese DIB Strengths and Dependencies

Mineral Type	China's Strengths	China's Dependencies (Country)
Iron and ferro-alloy metals	• Vanadium • Molybdenum	• Niobium (Brazil) • Cobalt (Congo) • Chromium (South Africa) • Tantalum (Congo)
Nonferrous metals	• Gallium • Germanium • Tellurium • Rare earth elements • Antimony • Arsenic	• Beryllium (United States) • Lithium (Australia)
Precious metals		• Rhodium (South Africa) • Platinum (South Africa) • Palladium (Russia and South Africa)
Industrial minerals	• Graphite • Fluorite	• Boron (Turkey and United States) • Zirconium (Australia)

SOURCE: RAND analysis of *World Mining Data 2020*.

China does not report the extent of its stockpiles on any of these raw materials. Additionally, there is no authoritative data source to estimate the rate of consumption for these materials for China in general and its DIB in particular. Understanding how long China's DIB might be able to sustain operations if China is denied access to any of these materials would be a crucial next step in this analysis and likely one that the intelligence community would need to support.

8. Conclusions

Our study revealed several strengths and vulnerabilities in China's DIB and several areas in which China is reliant on the United States and U.S. allies.

The Sheer Size of China's DIB Makes It Relatively Opaque to the United States and Unwieldy for the PRC

China's DIB is extensive, making an examination of deep structural problems difficult for outside analysts. Lack of transparency is another limitation, as it is in any closed society, but for China this challenge is exacerbated by our assessment that in some areas even the central government lacks transparency into its own SOEs and other DIB suppliers. Lack of transparency is not merely our own difficulty; it is China's as well.

This lack of transparency makes it difficult to assess the relationships between and among firms inside and outside the DIB, including SOEs and other types of enterprises and organizations in dual-use sectors. China's system of *guanxi*—the networks of social relationships used to facilitate management, business deals, and party directives—is opaque to outside observers. These relationships—including at the individual person and firm levels—would illuminate why certain firms receive favor in the DIB, including beneficial contracts. As managers move between firms and officials move between the party and positions throughout the DIB, *guanxi* are among the strings being pulled from behind the scenes. A greater understanding of these relationships and favors would provide insights that are currently not known even to many within China's DIB who themselves may lack visibility into relationships they are not personally party to.

Additionally, we were unable to find research that adequately described the nature of a "privately owned enterprise" in China and its role in the DIB. In the United States, this concept is clear, but we chose not to apply our U.S. definitions (or mirroring bias) to China's enterprises. A greater understanding of the nature, ownership structure, organization, and other elements of China's POEs would benefit future users of our methodology, as well as U.S. policymakers.

China's DIB Both Benefits and Suffers from the Effects of Single-Party Dominance of Government

China's centralization of power and decisionmaking supports its ability to drive whole-of-government strategies, set priorities, and align government actions around its priorities in ways the U.S. government is unable to do. China can create global approaches to its priorities, whereas the U.S. government must take more fragmented or piecemeal actions in the absence of affirmative interagency processes. But the ability of the Chinese government to lead with one voice creates a weakness for the country when the entire DIB pivots toward the new priorities to the detriment of other matters that might fall by the wayside. In short, Xi can do anything, but he cannot do everything. Topics outside the priority list risk anemic treatment without the leadership's spotlight. This challenge is a risk for China should the government bet on the wrong technology or shine its light too brightly on one aspect of its DIB and leave another in the dark.

This challenge for China is exacerbated by the CCP's recent activities to exert greater central control on market-oriented reforms. The CCP, led by Xi, risks inhibiting innovation by fostering an environment in which entrepreneurs avoid potential reproach by leadership. In general, the mutual desire for both (1) influential party control employing cadres and campaign approaches to achieve goals on the one hand and (2) a more entrepreneurial, innovative managerial culture on the other may be one of the most meaningful contradictions that might roil under the surface of the DIB in the coming decade.

China Is a Global S&T Power, Yet the Chinese Defense Innovation System Suffers from Weak Linkages Between Elements and Dependency on Foreign Inputs

China is no longer an "emerging" S&T power; rather, it is competing with the United States for global S&T primacy. On measures of scientific output, China and the United States compete closely for the top ranking. In patented military technology, China has a quantitative advantage relative to the United States, even after adjusting for patent quality.

However, China's defense innovation system suffers from weak linkages between system components. Linkages among government S&T organizations, enterprises, and research organizations are observed to be weak, indicating that the system does not effectively transmit knowledge and information between components. China's defense innovation system also remains dependent on foreign countries—including the United States and U.S. allies—in many areas, including education, material imports, and IP. The sheer scale of China's practices for gathering these resources—education and IP—from foreign countries indicates the country's own view of these areas as domestic vulnerabilities.

Although China's Manufacturing Capacity Looks Strong, There Are Clear Dependences That Indicate Potential Weakness

China runs large trade deficits with East Asia and Europe in manufacturing. China is the world's leading importer of most bulk commodities, and there are high-tech imports that sustain the manufacturing base.[225] As the "world's workshop," China imports intermediate goods and

[225] World Trade Organization, *Trade Profiles*, 2019, pp. 80–81.

components to produce finished electronics, vehicles, and other goods. Additionally, there is a revealed dependence on imported computer numerical control (CNC) milling machines and precision measurement tools, such as photo-optical image readers, to allow China's automated manufacturing processes to function smoothly. These trade flows are an impetus behind the "Made-in-China 2025" plan to alleviate the growing volume of high-tech imports and prevent a shrinking trade surplus from turning into a deficit.

China's reliance on manufacturing imports places importance on a select few nations that have an oversized weight in China's trade portfolio. Among the top five manufacturing imports, different IC categories account for three of the five, vehicles account for a fourth, and biotechnology and pharmaceuticals (not bulk chemicals) account for the fifth category. South Korea, Taiwan, Japan, and the United States are significant players in the IC market, and ICs represent China's largest import category, exceeding even that of fuel and ore. In a sense, ICs are like the petroleum of the 20th century and the coal of the 19th century to China's economic engine. It may seem paradoxical that China also exports ICs in large numbers, but China has leaned on highly developed East Asian economies to import smaller, more efficient ICs (currently at the 7-nanometer size) while exporting larger, more common ICs.

In terms of the DIB, China remains dependent on Russia, Ukraine, and, to a certain extent, France for aircraft and naval engines despite its efforts to develop the capability domestically. Indeed, engines as a category represented the largest share of all Chinese arms imports between 2015 and 2020.

China Will Be Vulnerable to Significant Workforce Upheaval over the Next Ten Years

China's labor force will shrink over the next two decades. Fertility rates continue to drop, as throughout Asia, but leading economic drivers have been left unaddressed.[226] China's coming workforce pinch is complicated by China's large population and the extreme income disparities between the coasts and the interior. These longer-term trends might create future challenges for China not only regarding sheer workforce size but also in shifts in bargaining power—both bargaining power considered narrowly with regard to wages and working conditions, and considered more broadly with increased pressure for social spending from a more slowly growing GDP placing a squeeze on DIB procurement.

We found indications that China's DIB may struggle to attract and retain trained talent in the future. Research from Fudan and Tsinghua universities shows that a third of recent graduates, regardless of whether they were educated at home or abroad, quit their first job within six

[226] One demographic driver, the modified One-Child Policy, has been considerably relaxed yet still remains on the books as a potential element of control (Junsen Zhang, "The Evolution of China's One-Child Policy and Its Effects on Family Outcomes," *Journal of Economic Perspectives*, Vol. 31, No. 1, Winter 2017).

months of graduation because of unmet career expectations. SOEs make up the majority of the DIB, and though they have long been regarded as desirable employers, they are historically resistant to change, even when directed by CCP leadership. Assuming this trend holds true, DIB firms may struggle to meet the growing career expectations of the emerging workforce and as a result struggle to retain top-tier talent.

Suggested Information Requirements to Improve Assessment of China's DIB

Section 1260C of the FY21 NDAA also asked for identification of "intelligence and other information requirements" that might address foreign DIB strengths and weaknesses generally and for China in particular. In this section, we provide several information requirements that would improve these assessments—beyond those already noted in the prior section—based on the open-source data available.

When examining raw materials, we were unable to assess the size of China's stockpiles. Without the size of the stockpiles and information about the rate at which China uses a given material, we were unable to assess how long China can continue its current course or recover if the country lost access to any given material.

We found, in both secondary and primary sources, a lack of data and analysis about DIB sectors that provide both services and software to the PLA. In the United States, these firms frequently provide ongoing logistics support of major military systems, information systems, and other defense services. The same firms that provide products often also provide the services to maintain those systems, and we can assume that these same skills would reside in China's SOEs. But we lack data about the size of the DIB services components distinct from products, the services being provided and their quality, and whether the SOEs are providing services or the PLA is servicing its own systems.

We were unable to find data or analysis on the size and quality of the DIB software industry. For software that is tied directly to hardware systems—such as the guidance system for a missile—we could make certain assumptions about the software's quality based on the effectiveness of underlying hardware (e.g., accuracy). For software not associated with one system, such as applications for integration across command, control, communications, intelligence, surveillance, and reconnaissance (C4ISR) systems, we could draw no conclusions.

We found no systematic analysis of the flow of Chinese students and researchers out of China to foreign universities *and back*. Much research and analysis on this topic is anecdotal—using individual examples to understand common tactics—but these analyses prevent an understanding of how specific Chinese institutions or programs are engaging with specific non-Chinese institutions or programs to feed talent directly into the Chinese DIB.

Appendix A. Fiscal Year 2021 National Defense Authorization Act, Section 1260C

The following is Section 1260C from the FY21 NDAA, in its entirety.

SEC. 1260C. ESTABLISHMENT OF CAPABILITIES TO ASSESS THE DEFENSE TECHNOLOGICAL AND INDUSTRIAL BASES OF CHINA AND OTHER FOREIGN ADVERSARIES.

(a) ASSESSMENTS.—The Secretary of Defense, in coordination with the heads of other Federal departments and agencies as appropriate, shall define intelligence and other information requirements, sources, and organizational responsibilities for assessing the defense technological and industrial bases of foreign adversaries and conducting comparative analyses of such technological and industrial bases with respect to their resilience and capacity to support their strategic objectives. The requirements, sources, and responsibilities shall include—

(1) examining the competitive military advantages of foreign adversaries, including with respect to regulation, raw materials, use of energy and other natural resources, education, labor, and capital accessibility;

(2) assessing relative cost, speed of product development, age and value of the installed capital base, leadership's technical competence and agility, nationally-imposed inhibiting conditions by foreign adversaries, the availability of human and material resources, and reliance on the industrial base of the United States or United States allies and partners;

(3) a temporal evaluation of the competitive strengths and weaknesses of United States industry, including manufacturing surge capacity, versus the directed priorities and capabilities of foreign adversary governments; and

(4) assessing any other issues that the Secretary determines appropriate.

(b) METHODOLOGY.—The Secretary of Defense shall incorporate inputs pursuant to subsection (a) as part of a methodology to continuously assess domestic and foreign defense industries, markets, and companies of significance to military and industrial advantage to identify supply chain vulnerabilities.

(c) CONDUCT OF ASSESSMENT WORK BY INDEPENDENT ORGANIZATION.—

(1) Agreement authorized.—The Secretary of Defense is authorized to enter into an agreement with an independent organization to carry out some of the assessment work required under subsections (a) and (b).

(2) Notification.,—If the Secretary enters such an agreement, the Secretary shall, not later than March 15, 2021, provide to the congressional defense committees a report identifying the organization and describing the scope of work under the agreement.

(d) REPORTS.—

(1) Initial report.—Not later than March 15, 2021, the Secretary of Defense shall submit to the congressional defense committees a report on efforts to establish the continuous assessment activity required under subsections (a) and (b), including a notification if the Secretary engages an independent organization, pursuant to subsection (c), to prepare the report described in paragraph (2).

(2) Subsequent report.—

(A) In general.—Not later than August 1, 2021, the Secretary shall submit to the congressional defense committees a report on the first assessment required under subsections (a) and (b) with respect to the People's Republic of China.

(B) Elements.—The report required by subparagraph (A) shall include—

(i) the information described in subsection (a);

(ii) any exclusive or dominant supply of military and civilian material, raw materials, or other goods (or components thereof) essential to China's national security by the United States or United States allies and partners;

and

(iii) the availability of substitutes or alternative sources for goods identified under clause (ii).

(3) Inclusion of independent organization’s assessment work.—If the Secretary enters into an agreement with an independent organization under subsection (c), the Secretary shall include the assessment work carried out by the organization under the agreement without change, but may include comments with respect to such assessment work.

Appendix B. Assessment Methodology for a Foreign DIB

This appendix presents a methodology for assessing a foreign country's DIB that could be applied to any country and would reveal the systemic strengths and vulnerabilities of that country's DIB. The methodology presented in this appendix considers that some countries have open societies with competitive commercial marketplaces, whereas other countries rely on SOEs; some countries have vibrant R&D and advanced manufacturing sectors, whereas other countries rely on importing foreign-made weapon systems.

In each section below, we present a framework for assessing each of the six topics (defined in Table 1.1), then a method for operationalizing that framework to conduct an assessment.

Our methodology is designed to assess the strengths or vulnerabilities of a country's DIB relative to its stated goals. Therefore, this methodology should begin with an understanding of a country's strategic priorities, including its national and military priorities. This understanding can be gleaned from documents, statements, and speeches by senior government officials and from an assessment of how the stated goals articulated in such artifacts differ from the implied goals of the country that can be gleaned from other sources in each of the six areas of this methodology.

When we applied this methodology to China, we presented only the findings that were useful in assessing China's strengths and vulnerabilities. As a result, aspects of the methodology presented in this appendix would be relevant to other countries, even though they are not included in the chapters of this report about China.

B.1. Economics

We begin a methodology designed to reveal the strengths and vulnerabilities of a foreign country's DIB with economics. In the late 19th century, a nation's industrial base emerged as a decisive determinant of military capability.[227] In the 21st century, this factor is as decisive as ever but also more difficult to characterize.[228] While the capacity of a nation's industry—and its ability to design, develop, fabricate, and sustain technologically advanced platforms and systems—has become paramount, defining what constitutes that DIB has become less certain as the materials, componentry, and technologies that make up military systems often emerge from

[227] A century earlier, the first U.S. government document explicitly concerned with the capabilities and policies surrounding the DIB was arguably Secretary of the Treasury Alexander Hamilton's 1791 *Report on Manufactures*.

[228] See, for example, Chapters Three and Six in Howard J. Shatz and Nathan Chandler, *Global Economic Trends and the Future of Warfare: The Changing Global Environment and Its Implications for the U.S. Air Force*, Santa Monica, Calif.: RAND Corporation, RR-2849/4-AF, 2020.

partially or completely civilian plants and sectors.[229] Therefore, a nation's DIB will have a different character and scope prior to conflict, during hostilities of short duration, and under extended wartime conditions.[230] As described in Chapter 1, the analysis in this study focuses on peacetime characteristics.

Framework

Four categories provide a framework for assessing the economic factors affecting DIB performance. National differences in endowments of natural resources have long been an aspect of economic focus. We broaden the concept to consideration of *fundamental endowments*, including aspects of a national setting relevant for DIBs. A *macroeconomic* perspective is useful for measuring economy-wide factors that could affect DIB inputs, outputs, and performance. Applying a traditional *microeconomic* approach in parallel fleshes out the portrait by considering how specific markets, industrial sectors, and performers both inside and outside the DIB operate individually and interact with each other.

The last of four broad categories is somewhat less usual. It includes factors that speak to the dynamics of the DIB (and larger economy) in terms of its *resilience and capacity for transformation*. That is, how well might the DIB assess and recover from vulnerabilities, on the one hand, and how well is it suited for the dynamics of change, particularly technological innovation, on the other.[231] These factors could have been included under the previous headings, but including them as a fourth category raises them to a level of attention appropriate to their relevance to the fundamental purpose of the methodology.

Fundamental Endowments

The fundamental endowments of a nation represent its natural resources and characteristics, as well as aspects of setting that may have bearing on a nation's DIB. The following list provides the specific fundamental endowments that are most relevant to assessing the strengths and vulnerabilities of a DIB:

- **Population** lies at the heart of economic size, and hence DIB capacity.

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[229] In the United States, the Cybersecurity and Infrastructure Security Agency defines the DIB as "the worldwide industrial complex that enables research and development, as well as design, production, delivery, and maintenance of military weapons systems, subsystems, and components or parts, to meet U.S. military requirements." It notes that the base includes DoD components and private companies and their subcontractors, both domestic and foreign, among other entities (Cybersecurity and Infrastructure Security Agency, "Defense Industrial Base Sector," webpage, undated).

[230] John T. Correll and Collen Nash, "The Industrial Base at War," *Armed Forces Journal International*, Vol. 48, 1991. This article provides a good illustration of changes in the U.S. DIB during the short-duration Gulf War.

[231] This represents an economics-centric compilation of several capacities for transformation discussed in Ashley J. Tellis, Janice Bially, Christopher Layne, Melissa McPherson, and Jerry M. Sollinger, *Measuring National Power in the Postindustrial Age*, Santa Monica, Calif.: RAND Corporation, MR-1110/1-A, 2000.

- **Labor participation** describes the size of the basic labor force without accounting for skills or education. Relatedly, the **dependency ratio** (dependents per worker) suggests capacity limits for further enhancing participation, and the actual size of the **industrial workforce** helps describe costs and limits on DIB capacity.[232] **Military participation** further describes the potential workforce not available for labor or training in the DIB.
- **Energy and raw materials** will be treated in detail in Section B.6, "Raw Materials."
- **Geopolitical constraints** include factors such as long-standing alliances, enmities, or other relationships that could affect the DIB resilience or vulnerabilities with respect to imports, exports, or other forms of exchange, such as research alliances and technology sharing.

Macroeconomic Factors

This category includes those aspects of a national economy that affect it as a whole and that have bearing on DIB performance and vulnerability. The following macroeconomic factors are most relevant to assessing the strengths and vulnerabilities of a DIB:

- **Size** of the economy is one determinant of fundamental capacity and ability for change. **GDP per capita** provides a rough assessment of the level of economic development and may have bearing on military success.[233]
- **Sectoral output** composition is a rough proxy for the level of industrialization, and **income and wealth distributions** provide insight into issues that might arise in social organization.
- **Monetary and price stability** affects the ability to plan production throughout the economy, and availability and prevailing conditions for **finance** are indicators for potential capital flow constraints on investment.
- **Defense effort** measures the scale of resources applied to military endeavors supported by the DIB, and the **defense burden** this represents is a marker of the priority given to military expenditures.
- **Senior-level priority** choices bring the policy component of economic activity into view, as do more detailed determinations of means used to enforce those priorities. (This will be treated in detail in Section B.2, "Governance and Regulations.")
- **Infrastructure** represents the systems and fixed capital necessary to support economic activity and specifically comprehensive, timely, and effective delivery of materials to, from, and within the DIB.[234]

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[232] The dependency ratio can be divided into two ratios: A *youth-dependency ratio*, measuring the ratio of people ages 0–14 to people ages 15–64, and an *old-age* or *elder dependency ratio*, measuring the ratio of people ages 65 and over to people ages 15–64 (United Nations, *Indicators of Sustainable Development: Guidelines and Methodologies—Third Edition: Methodology Sheets*, June 15, 2007, pp. 104–106).

[233] Michael Beckley, "Economic Development and Military Effectiveness," *Journal of Strategic Studies*, Vol. 33, No. 1, 2010.

[234] Notably, the 1956 law enabling the U.S. Interstate Highway System is popularly known as the National Interstate and Defense Highways Act of 1956, although *Defense* is not part of its formal name (Public Law 84-627, Federal Highway Act of 1956, June 29, 1956). Defense and civil defense purposes were noted during the two years of debate leading to the law (Richard F. Weingroff, "Original Intent: Purpose of the Interstate System 1954–1956," webpage, updated July 27, 2017).

- **Legal and institutional frameworks** will be treated in detail in Section B.2, "Governance and Regulations." One of the more important aspects is the confidence of being able to enforce a contract in a court of law. Given the importance of technology in modern weapon systems, another important aspect is the protection of IP as an incentive to innovate. Weak IP protections can inhibit developing a fully networked DIB and the willingness of private producers to enter into contracts for supply or delivery with DIB entities.

Microeconomic Factors

Microeconomic factors provide a description of the DIB itself and the sectors and firms of the civilian economy upon which it draws. The following microeconomic factors are most relevant to assessing the strengths and vulnerabilities of a DIB:

- **Production and industrial organization** lay out the sectoral structure of the domestic DIB and its capacity to meet the needs of the military customer. **Imports and exports** of materials, components, systems, and IP describe the degree of current dependence on foreign supply and markets.
- **Share of productive capacity** within the DIB allows for comparison with the civilian economy and understanding the capacity that might support a surge of DIB production. This may be supplemented with laying out the **production and industrial organization** sectoral structure of the non-DIB civilian economy along with its own current dependence on **imports and exports** of materials, components, systems, and IP.
- Examination of **DIB-civilian** interdependence in terms of actual flows of dual-use or defense-dedicated intermediary deliveries details the domestic capacity to meet the needs of the military customer. The **dependence on foreign trade** for these flows is another measure of foreign exposure and potential vulnerability for DIB activity.

Resilience and Capacity for Transformation

The factors under this category describe the ability of the DIB to rebound from adverse events and to adapt. While qualitative assessments appear throughout the methodology, these factors are especially difficult to quantify in a manner that conveys their essence, so qualitative measures are often required. Aspects directly associated with innovation and R&D will be treated in detail in Section B.3, "Research, Development, and Innovation." Measures for assessing the capacity for resilience and transformation of a DIB include the following:

- **Total factor productivity** is the most common measure of technological change at a national level. It measures that part of production not accounted for by growth in material, capital, or labor inputs. Data may be present to determine this value at the level of industrial sectors.
- Metrics for measuring the scale of **corruption** assist in understanding weaknesses at the managerial level, while other metrics of **leadership efficiency** assist in assessing strengths. Another indicator of managerial capacity for decisionmaking would be to

assess the balance of **incentive and risk** confronting managers within sectors included in the DIB to better understand systemic propensity toward innovation.[235]

- **Workforce skill development** is treated in detail in Section B.4, "Workforce, Labor, and Skills." Beyond basic skills formation, **skills uptake** is important to the DIB: Can trained personnel find employment in the DIB or otherwise put learned skills to use? **Skills mobility** as measured by movement of personnel across firms or sectors is also important for the diffusion of capabilities and the development of networks of knowledge and application.
- **Efficiency and effectiveness** embrace the concept that demands on the DIB vary depending on policy priorities over time. Efficient use of resources is desirable as long as the DIB is effective in supporting military capabilities. This factor provides a portal for assessors to characterize a country's DIB for strengths and weaknesses along this dimension but is notoriously difficult to quantify.
- **Response to external change** also provides a portal for assessing a DIB based on its characteristic ability to monitor, assess, and respond to signals of change arising outside of the domestic policy-action axis.

Method

Table B.1 presents measures for assessing the factors described above. Assessment of any DIB might include a parsimonious set of these measures suited to the specific setting to provide insight into economic conditions affecting a nation's DIB. Initial applications of the methodology to a foreign DIB may serve to set a baseline against which changes in the economics of a DIB over time might be better assessed and clearer inferences drawn.

Table B.1 provides a list of the proposed measures across the four categories that make up the scope of economic factors. For each measure, the list provides a suggested metric and potential data source. Measurements related to resilience and transformation factors rely more on case studies and qualitative analyses than reportable time series data. Similarly, while other measures (e.g., GDP, total factor productivity) may be readily obtainable, their concreteness may mask issues salient enough to require qualitative assessment for most accuracy. For example, scale of the informal economy or known biases of statistical agencies might color GDP calculations, while total factor productivity, usually treated as a measure of technical improvement, quite literally measures the influence of all input factors not otherwise specified and so may reflect other phenomena as well.

[235] Steven W. Popper, Marjory S. Blumenthal, Eugeniu Han, Sale Lilly, Lyle J. Morris, Caroline S. Wagner, Christopher A. Eusebi, Brian Carlson, and Alice Shih, *China's Propensity for Innovation in the 21st Century: Identifying Indicators of Future Outcomes*, Santa Monica, Calif.: RAND Corporation, RR-A208-1, 2020.

Table B.1. Economics Measures

Category	Measured Concept	Metric	Sources
Fundamental endowments	Population	• Size of population	• World Bank
	Labor participation	• Total labor force share of population	• World Bank
	Dependency ratio	• Youth dependency ratio • Elder dependency ratio	• World Bank • U.S. Census Bureau International Data Base
	Industrial workforce	• Total labor force share in industry	• World Bank
	Military participation	• Total military forces share of total labor force	• World Bank
	Geopolitical constraints	• International factors limiting or expanding opportunities for DIB imports, exports, or substitutes	• Academic literature
Macroeconomic factors	Economy size	• GDP[a]	• World Bank
	Level of development	• GDP per capita	• World Bank
	Sectoral output	• Shares of output produced by agriculture, industry, services	• World Bank
	Income distribution	• Income Gini coefficient[b]	• World Bank
	Wealth distribution	• Wealth Gini coefficient	• Credit Suisse Research Institute, *Global Wealth Report*
	Monetary stability	• 10-year CPI time series • Index of public debt	• World Bank
	Financial market	• Real lending rates	• World Bank
	Scale of defense effort	• Annual defense budget	• World Bank
	Defense burden	• Defense share of GDP	• World Bank
	Senior level priority	• Assessment of official documents	• Domestic government sources • Academic literature
	Infrastructure	• Assessment of shortcomings affecting DIB	• Domestic journalism • Academic literature
	Legal and institutional	• Length of time to enforce contract	• World Bank
Microeconomic factors	DIB industrial organization	• DIB structure and flows	• Academic literature
	Production	• Scale • Sectorial breakdown • Comparison to non-DIB	• Statistical yearbooks • Academic literature
	Imports	• Scale • Sectorial breakdown • Comparison to non-DIB	• UN Comtrade • SIPRI • U.S. Department of State World Military Expenditures and Arms Transfers (WMEAT) reports
	Exports	• Scale • Sectorial breakdown • Comparison to non-DIB	• UN Comtrade • SIPRI • U.S. Department of State WMEAT reports

Category	Measured Concept	Metric	Sources
	DIB-civilian interdependence	• Deliveries between DIB and non-DIB producers and markets	• Private databases (e.g., Eora Global Supply Chain Database; FactSet financial data; Bloomberg)
	External dependence	• Import share in non-DIB deliveries to DIB	• UN Comtrade • Private data bases (e.g., EORA; FactSet; Bloomberg)
Resilience and transformation factors	Technological change	• Total factor productivity	• Organisation for Economic Co-operation and Development OECD.Stat
	Corruption	• Bribery incidence • Corruption Perceptions Index	• World Bank • Transparency International
	Managerial efficiency	• Qualitative assessment derived from reported cases	• Case studies from academic literature, journalism, social media
	Balance of incentive and risk	• Attitudes toward entrepreneurial risk • Willingness to delegate authority	• World Bank, TCdata360: Open Trade and Competitiveness Data • Global Entrepreneurship Monitor
	Skill uptake	• Unemployment among skilled, technically trained workers	• Case studies from academic literature, journalism, social media
	Skill mobility	• Movement between DIB, non-DIB • Movement across DIB sectors	• Case studies from academic literature, journalism, social media
	Efficiency/effectiveness	• Change in value added/ worker	• World Bank
	Response to external change	• Case studies	• Case studies from academic literature, journalism, social media

[a] GDP can be reported in different ways: (1) in DIB domestic currency, converted to USD at rates established in foreign exchange markets, or (2) converted by using purchasing power parity, that is, by an exchange rate established through comparing the total costs of two identical baskets of goods as purchased in each country. Each serves its purpose and provides different insights, so reporting all three is best for achieving a wider perspective.

[b] The Gini coefficient is a statistical relationship measuring the equality of distribution across a population ranging from 0 (complete equality) to 1 (complete inequality).

Some measures are easier to quantify than others, and some may be difficult to come by. Subsequent applications of the core methodology may be reconfigured to enhance sensitivity or respond to changed availability of data regarding these concerns. But it is purposeful to present them explicitly; inability to measure adequately does not reduce the importance of the underlying factors for assessing DIB strengths and vulnerabilities.

B.2. Governance and Regulations

Framework

We approached governance and regulations by examining how a country's laws, regulations, policies, and international agreements affect a DIB. We did not find any studies in our literature review that provided a holistic examination of the governance and regulations of DIBs, but several of the reports addressed specific narrow issues within governance, such as technology transfer, export-control frameworks, and corruption. Using the literature, we developed a list of topics that describe how governance and regulations interact with and affect a DIB:

- technology transfer and IP protections
- imports
- exports
- defense spending
- acquisition and procurement policies, processes, and oversight
- corruption
- labor issues.

Some of these topics are directly tied to other sections of our methodology, such as technology transfer (Section B.3, "Research, Development, and Innovation") or labor issues (Section B.4, "Workforce, Labor, and Skills"). Other topics are cross-cutting, such as corruption. We took this bottom-up approach of identifying these seven categories rather than a top-down approach of looking at a country's entire governance ecosystem because the latter would have been too broad to yield useful results in identifying vulnerabilities in a country's governance of its DIB.

Method

We used the above list to create research questions that would indicate whether governance is creating strengths or weaknesses for a country's DIB. The complete list of these research questions is provided in Table B.2.

Table B.2. Governance and Regulations Research Questions

Category	Research Questions
Technology transfer and IP protections	• What mechanisms govern technology transfer between the military and civilian sectors? What are these mechanisms' strengths and weaknesses/vulnerabilities? • How do IP protections strengthen or create vulnerabilities for the DIB?
Imports	• For defense technologies (or raw materials) for which the country relies on imports, have tariffs, sanctions, or other forms of regulation hindered access to the market? What are the strengths and weaknesses/vulnerabilities of relying on these imports? • What steps has the country taken to strengthen relationships with countries that are key sources of critical defense imports? What vulnerabilities exist in these relationships?
Exports	• What is the country's export control framework, and does the DIB believe this framework strengthens or weakens its organizations? Does this framework create monopsonies, and, if so, what vulnerabilities does this create? • In what ways (if any) has the state used defense exports as a tool to develop foreign relationships? Which of these relationships are the weakest and most vulnerable? Which are the strongest? • To what extent does the state rely on military exports for revenue? Which exports create the greatest revenue?
Defense spending	• How reliable is military spending, as perceived by the DIB? (e.g., are military budgets easily forecasted year to year, invoices paid on time) • For dual-use providers of military and civilian products and services, what are the benefits and disadvantages of contracting with the government compared with solely providing to civilian markets? • What are the country's long-term goals for subsidizing specific sectors of its DIB? What are the indicators that the country is achieving or failing against these goals?
Acquisition and procurement policies, processes, and oversight	• What vulnerabilities exist within the acquisition and procurement policies, processes, and oversight mechanisms? What are potential effects (or repercussions) of these vulnerabilities? • Does the country effectively identify, address, and monitor corruption in acquisition and procurement? Explain the strengths and vulnerabilities of these processes. • What incentives and disincentives exist for companies contracting with the government? • Describe any specific products and services where monopolies, monopsonies, or unhealthy levels of competition affect the product or service's quality and costs.
Corruption	• How does corruption affect the military and the DIB? Does the country effectively identify, address, and monitor corruption? Explain the strengths and vulnerabilities of these processes.
Labor issues	• What programs has the government created (or laws passed or other actions taken) to address labor market vulnerabilities in the DIB? (e.g., incentivizing STEM education, creating talent programs for critical skills) • What vulnerabilities in the labor market remain unaddressed? (e.g., forced labor, unsafe working conditions, nepotism, cronyism)
Overarching laws	• What are the ramifications of laws that have been passed that affect the DIB, which do not fall into any of the categories above? • To what extent do the country's governance and regulations differ on paper versus in practice? How does this gap (between law and reality) create strengths or vulnerabilities for the country?

We developed this list by beginning with areas in which governance and regulations have affected specific countries' DIBs and then generalizing those examples to globally relevant research questions. For example, a study on Russia's defense technology sector identified that "technology brokers" have been conducive to transfer technology from military to civilian industries, and the same study also assessed that the Russian defense industry lacks a clear patent and licensing policy and clear IP protections and that these are major impediments to military-civilian technology transfer.[236] This research led to our development of the questions under the category "technology transfer and IP protections."

The research question in the defense spending category about subsidies was directly inspired by two studies, one on the United States and another on Israel. A RAND study of the heavy-lift space launch market found that the U.S. market could not sustain itself without the U.S. government as a customer, effectively subsidizing the market.[237] The study of Israel noted that the country's former Minister of Defense wanted Israel's defense industries to privatize and sustain themselves by exporting products.[238] These two differing goals and situations indicated that the subsidizing of a DIB is neither good nor bad on its face, but rather analysts should assess whether the country is reaching the goals it set for itself and at what costs.

The greatest limitation to this methodology is that it is largely qualitative. For a method designed to be applied globally, a qualitative assessment is more challenging to apply than a quantitative assessment—data will not be structured. Analysts will need to rely on data sources that examine a country's organizations, institutions, laws, and practices. Therefore, we designed the research questions to prime analysts on what to consider in their examinations.

Analysts applying this methodology should use a variety of qualitative sources, such as publicly available laws, regulations, and strategy documents from the target country, along with the views and opinions of individuals who work within the DIB, such as scientists and executives. Many of these personal opinions might be publicly available as these persons lobby to the government to change rules or regulations or to reduce corruption or discourage other practices. Most of the data that are useful in the governance section might be country-specific, rather than come from global data sets.

We considered using a range of global quantitative governance measures—indices—that have been developed by political scientists and economists. These indices are developed using rigorous, transparent coding standards to score countries on different attributes, such as the level of corruption or the strength of IP protections. However, we judged that they offer scales of relative comparisons from country to country without directly informing an analyst of specific vulnerabilities in how a foreign DIB is governed and regulated.

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[236] Tor Bukkvoll, Tomas Malmlof, and Konstantin Makienko, "The Defence Industry as a Locomotive for Technological Renewal in Russia: Are the Conditions in Place?" *Post-Communist Economies*, Vol. 29, No. 2, 2017.

[237] Bonnie L. Triezenberg, Colby Peyton Steiner, Grant Johnson, Jonathan Cham, Eder Sousa, Moon Kim, and Mary Kate Adgie, *Assessing the Impact of U.S. Air Force National Security Space Launch Acquisition Decisions: An Independent Analysis of the Global Heavy Lift Launch Market*, Santa Monica, Calif.: RAND Corporation, RR-4251-AF, 2020.

[238] Uzi Rubin, "Israel's Defence Industries: An Overview," *Defence Studies*, Vol. 17, No. 3, 2017.

B.3. Research, Development, and Innovation

Our focus on the DIB restricts assessment to the actors, linkages, and institutional context responsible for the development and production of *military* technology innovation. Security scholars often combine technological and doctrinal innovation into a single construct: military innovation.[239] However, doctrine, while of clear import to national military power, is squarely outside of our conception of the DIB. The model proposed here does not include the drivers of doctrinal change; it focuses instead on the system elements that produce novel military technological innovation. This excludes civilian technologies that can be used by the military but are not uniquely intended for that application (e.g., personal computers, tablets, cybersecurity software).

Framework

With foundations in the national innovation systems (NIS) literature,[240] the contours of the NDIS are drawn by identifying the actors, linkages, and contextual factors that are of direct relevance to **new military technology** output.[241] Military technology is conceived broadly to include integrated weapon systems (e.g., a fifth-generation fighter aircraft), a system component (e.g., a new optical sensor integrated onto that fighter aircraft), nonweapon integrated systems (e.g., a military communications or surveillance satellite), components of nonweapon integrated systems (e.g., a synthetic-aperture radar antenna mounted on the satellite), and unembodied advancements such as software, waveforms, data links, and algorithms that are used in military systems. Figure B.1 depicts an NDIS and its output.

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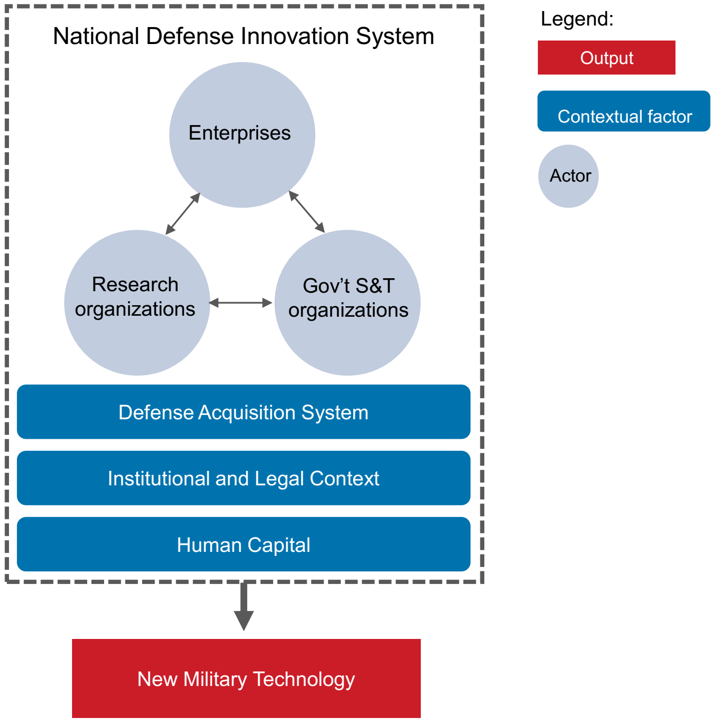
[239] Owen R. Coté, *The Politics of Innovative Military Doctrine: The U.S. Navy and Fleet Ballistic Missiles*, Cambridge, Mass.: Massachusetts Institute of Technology, 1995; Harvey M. Sapolsky, *The Polaris System Development: Bureaucratic and Programmatic Success in Government*, Cambridge, Mass: Harvard University Press, 1972.

[240] Christopher Freeman, "The Economics of Industrial Innovation," University of Illinois at Urbana-Champaign's Academy for Entrepreneurial Leadership Historical Research Reference in Entrepreneurship, 1982; Christopher Freeman, *Technology Policy and Economic Performance: Lessons from Japan*, Pinter Publishers, Ltd., 1987; Bengt-Åke Lundvall, *National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning*, London and New York: Pinter Publications, Ltd., 1992; Richard R. Nelson, *National Innovation Systems: A Comparative Analysis*, Oxford: Oxford University Press, 1993.

[241] Cheung, 2013; Cheung, 2018a. Cheung (2013, 2018a) has applied the NIS framework to military innovation. Popper et al. (2020) have drawn from the NIS literature to build a model of Chinese innovation potential and innovation propensity.

Figure B.1. National Defense Innovation System



The NDIS contains three major actor types: research organizations (R), enterprises (E), and government S&T organizations (G). This division of actors is based on the distinct functional contributions of these organization types within the system. Domestic **research organizations** contribute to scientific and technological research output. Such research need not anticipate a military application; rather, any research that makes its way into a military technology represents a functional contribution of the research organization to the NDIS.[242] The most common research organizations are universities, but government labs and private firms also contribute meaningfully in many countries.[243]

NDIS **enterprises** are those that contribute directly to the provision of new military technology. The principal functional contribution of enterprises to the NDIS is the provision of new operationally ready technology to a country's military. To this end, enterprises perform various functions, including conducting applied research, technology prototyping, testing and

[242] An argument could be made that because the scientific literature is largely available to global researchers, the focus on *national* S&T output is unwarranted. We make the distinction because of the documented importance of tacit knowledge (knowledge not contained in journal articles that is possessed by the researchers themselves) to the national innovation base. See, for example, Jacqueline Senker, "The Contribution of Tacit Knowledge to Innovation," in Satinder P. Gill, ed., *Cognition, Communication and Interaction*, London: Springer, 2008.

[243] Because the three NDIS performer types are defined based on their functional contributions, certain types of organizations can occupy more than one niche depending on their functional contributions. When a firm engages in basic research, it is acting as a research organization. When a firm engages in the commercialization of research for some military technology end, it is acting as an enterprise.

evaluation, user testing, and manufacturing. In many countries, SOEs play a significant role in the NDIS.

The **government S&T organizations** component of the NDIS is defined as a country's domestic government organizations that are focused on some aspect of scientific or technological discovery that directly contributes to new military technology. Of the three major actor types, the functional contribution of government S&T organizations is the most varied and would include providing public goods, funding research, serving a coordinating function, and addressing market failure. In practice, government agencies may take the form of defense labs, government technology listening posts, funding agencies, and organizations that provide testing and evaluation infrastructure for military technology.

Linkages represent the means of exchanging information and resources between organizations. Given the functional specialization of actor types, the existence, and health, of these linkages is critical to the effective functioning of the NDIS. In practice, linkages include flows of information and individuals between organizations, networks, collaboration, commercial relationships, funding channels, formal oversight responsibilities, publication of research findings, and university spin-off firms. Empirically, systems of innovation have been shown to depend on strong linkages between research organizations, enterprises, and government S&T organizations.[244]

NDIS organizations and linkages are embedded within three contextual factors. The **defense acquisition system** refers to government processes and organizational structures responsible for setting military requirements, allocating resources, and purchasing new military technology. Specific functions include the allocation of funding, source selection, contracting, setting technology performance requirements, vendor oversight, and shepherding technologies through the development, procurement, and sustainment processes.

The **institutional and legal context** in which the NDIS actors operate has several aspects. Formal legal codes, and the organizational apparatus required to implement them, that have been empirically linked to national innovative performance include IP rights regimes, contracting law, and regulatory regimes.[245] The institutional context refers to the constraints that shape political and economic behavior and include national and local political systems, norms, incentive structures,[246] and the rule of law.[247]

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[244] Henry Etzkowitz and Chunyan Zhou, *The Triple Helix: University-Industry-Government Innovation and Entrepreneurship*, Routledge, 2017.

[245] Peter A. Hall, and David Soskice, eds., *Varieties of Capitalism: The Institutional Foundations of Comparative Advantage*, Oxford: Oxford University Press, 2001; Jon Schmid and Seokbeom Kwon, "Collaboration in Innovation: An Empirical Test of Varieties of Capitalism," *Technological Forecasting and Social Change*, Vol. 157, August 2020.

[246] Popper et al., 2020.

[247] Douglass C. North, "Institutions," *Journal of Economic Perspectives*, Vol. 5, No. 1, 1991.

The NDIS **human capital** is embodied in individuals' knowledge, skills, and abilities that contribute to military technology innovation. All three of the actor types considered above draw on a country's pool of human resources to perform their functions within the NDIS. Human capital has been empirically linked to national innovative output.[248]

Method

Operationalizing the NDIS model for assessment requires measures of each of its elements along with the principal system output: new military technology. Table B.3 describes the ten concepts—nine system elements and one system output—and provides the metrics and data sources used to operationalize them. The remainder of this section describes the measurement approach for these ten elements in greater detail.

[248] Harald Badinger and Gabriele Tondl, "Trade, Human Capital and Innovation: The Engines of European Regional Growth in the 1990s," in B. Fingleton, ed., *European Regional Growth*, New York: Springer, 2003.

Table B.3. NDIS Measures

Category	Measured Concept	Metric	Sources
Research organizations (R)	Extent of the national S&T research base	Annual number of scientific publications	Web of Science
		Annual number of high-impact scientific publications	Web of Science
Enterprises (E)	Extent of enterprise participation in the military technology innovation process	Domestic organizations with at least 5 military patents	Web of Science: Derwent Innovation Index
Government S&T organizations (G)	Extent of government promotion of scientific and technological advancement	Annual government spending on R&D	National Bureau of Statistics of the People's Republic of China
		Annual defense spending on research, development, testing, and evaluation	Janes
R-E linkage	Strength of bilateral research organization–enterprise linkage	University-firm co-authorships	Web of Science
R-G linkage	Strength of bilateral research organization–government S&T organization linkage	Number of government agencies funding scientific research	Web of Science
		Concentration of scientific funding	Web of Science
E-G linkage	Strength of bilateral enterprise–government S&T organization linkage	Qualitative assessment of the extent to which a country's national government is taking action to engage its private sector in defense-related S&T activity	Various
Institutional and legal context	Extent to which national institutions and legal system support scientific and technological advancement	International Property Rights Index	Property Rights Alliance
		Regulatory quality	World Bank
Acquisition system	Extent to which defense acquisition system enables efficient military technology development	Qualitative assessment of the national defense acquisition system	Various
Human capital (S&T)	Size and quality of S&T workforce	Postgraduate degrees awarded	National Bureau of Statistics of the People's Republic of China, China Statistical Yearbook
		Number of students studying abroad	National Bureau of Statistics of the People's Republic of China, China Statistical Yearbook
New military technology	Size and technical character of NDIS output	Military patents (weighted counts)	Web of Science: Derwent Innovation Index

Category	Measured Concept	Metric	Sources
		Technological focus of military patents	Web of Science: Derwent Innovation Index

NDIS Actors

We measure research organizations using two metrics. *Scientific publications* are the annual number of scientific journal articles on which an organization located in the focal country is listed as an author's affiliation.[249]

The second metric is *high-impact publications*, calculated as articles that are in the top 0.1 percent for citations received. This measure accounts for the observation that there is systematic cross-national variation in the quality of published scientific journal articles.[250] Data to calculate both publication measures come from Clarivate's Web of Science citation database. We limit the search to the Science Citation Index Expanded (SCI-EXPANDED) database of Web of Science to omit contents from fields such as law, history, and the social sciences. Many journals indexed in Web of Science are written in English.[251] Given that English is currently the *lingua franca* for scientific publishing, language-based bias in data coverage will exist but is likely to be minimal.

To measure the extent of enterprise participation in the military technology innovation process, we calculate the *number of domestic patent assignees* (i.e., patent owners) that are listed on at least five military patents during the focal year. A domestic patent assignee is one whose principal business is based in the country in question.[252] Patent data come from Web of Science's Derwent Innovation Index, a database containing all patent grants from 52 distinct patent-issuing authorities (e.g., the U.S. Patent and Trademark Office, the China National Intellectual Property Administration, the European Patent Office).

To measure the extent of government organizations in the promotion of scientific and technological advancement, we use two metrics: *total annual government spending on R&D* and *defense spending on research, development, testing and evaluation*.

Linkages

To measure the strength of the research organization–enterprise (R-E) linkage, we calculate *university-firm co-authorship*: the number of publications on which an author from one of a

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[249] Because many publications are the result of international collaboration, some scientific publications will be counted more than once. We choose this approach—as opposed to a fractional counting method—because it facilitates interpretation. The scientific publications metric used here can be interpreted as the total number of scientific publications on which an author from the focal country contributed.

[250] Jon Schmid and Fei-Ling Wang, "Beyond National Innovation Systems: Incentives and China's Innovation Performance," *Journal of Contemporary China*, Vol. 26, No. 104, 2017.

[251] James Testa, "Journal Section Process," webpage, June 26, 2018.

[252] Technically, the patents used here are patent families: the set of international patents that cover a single invention. Failure to use patent families would result in double counting inventions that were simply filed in more than one patent jurisdiction (a common practice in patenting).

country's universities is listed with another author that is affiliated with one of that country's top 50 firms (ranked by R&D expenditure). We query the Web of Science for all publications published by any of a country's top 50 firms in terms of R&D expenditure ("The Global Innovation 1000 Study").[253] We then count instances of co-authorship between one of these firms and a domestic university. The total number of such instances that occur during a given year equals a country's *university-firm co-authorship* and is a measure of the strength of the R-E linkage.[254]

To measure the strength of the research organization–government S&T organization (R-G) linkage, we calculate the *number of government agencies funding scientific research* and the concentration of scientific funding. This number is extracted from the "funding" field from all of a country's scientific publications for a given year. We then clean this text field by consolidating like entries (e.g., "NSF" and "National Science Foundation"). The metric is calculated at the level of the parent organization; distinct institutes within a parent organization are counted at the level of the parent organization (e.g., the National Institutes of Health's [NIH's] National Institute on Aging is not considered a separate funding agency from the NIH).

To measure *concentration of scientific funding* we calculate the Herfindahl–Hirschman Index (HHI) for funding sources, which is calculated as the sum of the squared funded publication shares for funding sources within a country's research funding system. More formally, we calculate

$$Concentration\ of\ scientific\ funding\ = \sum_{1}^{N} s_i^2$$

where s_i is the funded publication share of the *i*th funding agency.

Funded publication share is the ratio of the number of publications on which a given funding agency is listed and a country's total number of publications for the year. We limit the calculation to funding agencies that have funded more than 100 publications during the year in question.

To measure the strength of the enterprise–government S&T organization linkage (E-G), we assess how a country's government S&T organizations engage with its domestic enterprises. Means of engagement include the formal issuance of requests for proposals, the announcement of open procurement competitions, high-level guidance and associated policy action on national S&T priorities, and initiatives or organizations explicitly aimed at engaging the private sector to participate in publicly funded S&T projects. Given this variety, the metric is not amendable to quantification. Rather, we propose qualitatively assessing *the extent to which a country's federal government is taking actions to engage its private sector in S&T activity*.

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[253] Strategy&, "The Global Innovation 1000 Study," webpage, 2018.

[254] Although countries vary greatly in size, restricting this measure to the top 50 R&D firms provides inherent normalization and therefore rough comparability across countries.

Contextual Factors

To measure a country's institutional and legal context, we focus on the subset of institutions and laws of most direct relevance to the NDIS (see Section B.2, "Governance and Regulations," for our methodology for assessing how broader national governance variables affect the DIB). Specifically, we evaluate the national system of property rights protection and the overall quality of the regulatory system. We use the International Property Rights Index produced annually by the Property Rights Alliance as a proxy for national property rights protection. We measure the overall quality of the regulatory system using the World Bank's Regulatory Quality composite measure.[255]

To assess a country's defense acquisition system, we qualitatively assess the performance of a country's processes for procuring military technology. To this end, we rely on news sources and the findings of other researchers.

To measure the size and quality of the NDIS-relevant workforce, we rely on two metrics: *postgraduate degrees awarded* and *number of students studying abroad*.

Output

To measure the extent and technical character of NDIS output, we use military patents. Military patents are defined using Derwent Class Code W07 (Electrical Military Equipment and Weapons). The overall size of new military technology output is measured as annual quality-adjusted counts of military patents.[256] There is well-documented international heterogeneity in patent quality. For instance, recent studies have found that Chinese patents are of lower quality than their international counterparts.[257] One study found that, on average, U.S. patents are cited 2.25 times more frequently than Chinese patents, suggesting higher impact of U.S. patents on subsequent technological change.[258] Given this heterogeneity, failure to adjust for quality would degrade the cross-national commensurability of the NDIS output metric. Here, we adjust the patent count data using the average patent family size for the country in question. For a given patent, *family size* is the number of jurisdictions in which the patent has been filed. Patents that are filed in multiple jurisdictions have been shown empirically to be of higher quality than those that are filed in a single jurisdiction.[259] We use the discounting formula proposed in Schmid

[255] Daniel Kaufmann, Aart Kraay, and Massimo Mastruzzi, "The Worldwide Governance Indicators: Methodology and Analytical Issues," *Hague Journal on the Rule of Law*, Vol. 3, No. 2, 2011.

[256] For a detailed explanation of the use of these data as a proxy for military technology, see Schmid, 2018.

[257] Christian O. Fisch, Joern H. Block, and Philipp G. Sandner, "Chinese University Patents: Quantity, Quality, and the Role of Subsidy Programs," *Journal of Technology Transfer*, Vol. 41, No. 1, 2016; Xibao Li, "Behind the Recent Surge of Chinese Patenting: An Institutional View," *Research Policy*, Vol. 41, No. 1, 2012.

[258] Schmid and Wang, 2017.

[259] Bhaven Sampat, *Determinants of Patent Quality: An Empirical Analysis*, Columbia University, Mailman School of Public Health and School of International and Public Affairs New York, 2005; Thomson Reuters, *Top 100 Global Innovators Report*, 2011; Schmid and Fajebe, 2019.

(2021) to discount each patent by the ratio of a country's average patent family size to the global average patent family.[260]

To measure the technical character of NDIS output, we assess the technological focus of a country's military patents for the focal year using a keyword-based approach. We search the titles and abstracts of a country's military patents for keywords and terms related to technology applications of interest.

The population of this framework— especially if compared with a relevant peer country or considered over multiple time periods—will allow a policymaker to gauge a country's domestic capacity to develop advanced military technology. It can also be used to identify country-specific DIB vulnerabilities and may reveal points of weakness in a country's domestic military R&D system. High values for the metrics used here to proxy NDIS components are indicative of a strong NDIS and are thus preferred to low values. Low values would point to system weaknesses or vulnerabilities.

B.4. Workforce, Labor, and Skills

Our methodology for assessing a nation's workforce, labor, and critical skills is built on three critical features. First, the method must identify critical vulnerabilities within the target nation's available workforce, labor, or skills. Second, the method must be flexible enough to account for differences in national strategic objectives. Third, the method must be repeatable and account for the changes in a nation's strategic objectives over time.

To that end, we chose to take the most complete methodology, based on our English- and Chinese-language literature review, and augment it to meet our needs. The result is an evaluation framework that focuses on labor and skills gaps within a nation's DIB workforce.

Framework

We leveraged the framework developed by RAND Europe in support of the European Defense Skill Partnerships (EDSP).[261] The EDSP's process provides a national-level evaluation of critical DIB skills, but its reliance on industry-expert interviews is difficult and time-consuming to replicate. Further, EDSP's evaluation of skill gaps in the European Union's DIB was the final product. EDSP's process examined areas such as national policy, which in our framework is handled elsewhere. We thus modified the EDSP's process to meet our needs. A visual representation of our framework is given in Figure B.2.

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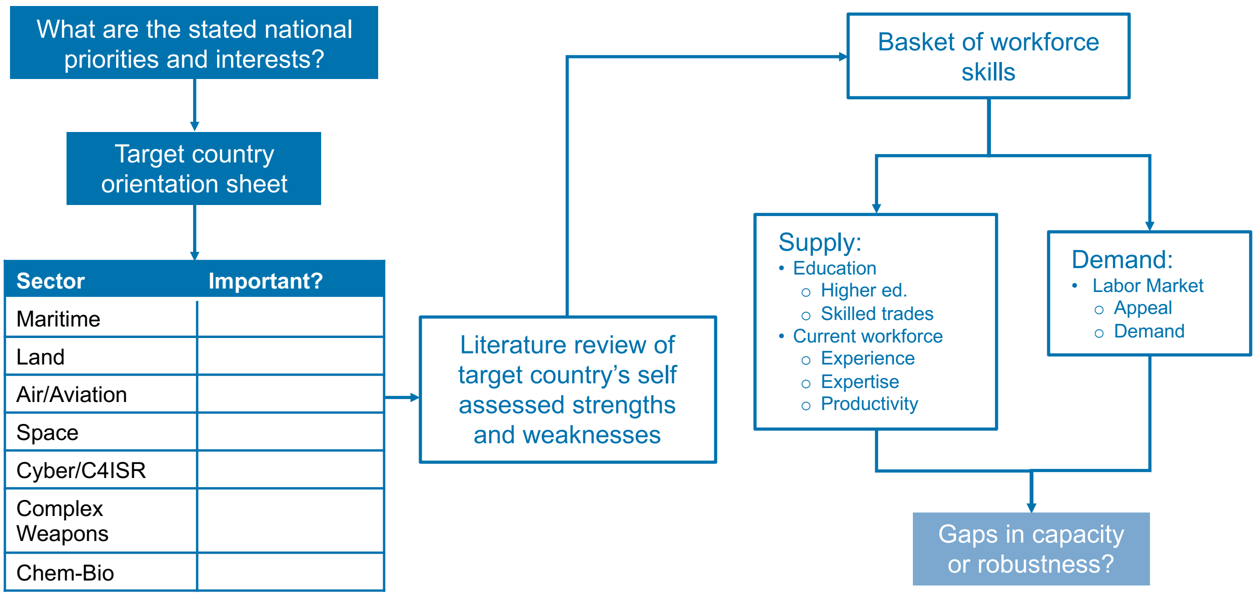
[260] Jon Schmid, *An Open-Source Method for Assessing National Scientific and Technological Standing: With Applications to Artificial Intelligence and Machine Learning*, Santa Monica, Calif.: RAND Corporation, RR-A1482-3, 2021.

[261] Katerina Galai, Lucia Retter, Julia Muravska, Marta Kepe, Alice Lynch, Anna Knack, Jacopo Bellasio, Antonia Ward, Arya Sofia Meranto, Davide Maistro, et al., *Understanding Skills Gaps in the European Defence Sector*, Santa Monica, Calif.: RAND Corporation, RB-10094-EC, 2020.

Our framework begins by evaluating the target nation's known strategic goals. We will leverage the initial literature review of the country of interest's defense white papers, national strategy documents, national defense law, and other sources to create a list of national strategic priorities.

Figure B.2. Workforce, Labor, and Skills Framework



SOURCE: Derived from Alice Lynch, Jacopo Bellasio, Katerina Galai, Marta Kepe, and Anna Knack, *Technical Annex, Methodologies—Annex to Report: Vision on Defence-Related Skills for Europe Today and Tomorrow*, European Commission, 2019b.

We then leverage the EDSP's process for mapping national demand to six defense sectors.[262] The EDSP's process uses the five warfighting domains; maritime, land, air, space, cyber and C4ISR, and adds complex weapons as a sixth category.[263] The benefits of the EDSP's categories are that they preserve the difference in DIB focus between nations. These differences add important context for evaluating a DIB's ability to meet strategic goals. For example, France has broad global commitments that translate into demand in all six categories in the EDSP study. Denmark, on the other hand, is only focused on air and complex weapon systems based on its strategic situation.[264] Attempting to measure Denmark by France's yardstick could make Denmark's DIB appear weaker than it is, and vice versa for France. We have added a seventh

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[262] Lynch et al., 2019b, pp. 2–5.

[263] Alice Lynch, Jacopo Bellasio, Katerina Galai, Marta Kepe, and Anna Knack, *Defence-Related Skills: Building Evidence on Skills Shortages, Gaps and Mismatches and Defining the Sector's Strategy on Skills*, Brussels, Belgium: Executive Agency for Small and Medium-Sized Enterprises, 2019a, pp. 30–32.

[264] Lynch et al., 2019b, p. 32.

sector, chemical and biological weapons, to account for nations that incorporate such weapons into their national security strategy.

Method

Using the critical sector list created in the framework, we move to identify critical skills within each of the critical DIB sectors. Any given industry has dozens of skill sets, some of which are specific to the industry and others that are universally in demand. We reduce this number to a tractable number by focusing skills that the target nation has identified as critical gaps within their DIB. An alternative method, assuming sufficient time and funding, is to apply solicit industry subject-matter experts using the Delphi method. A Delphi approach may be better able to identify gaps of which the target nation is unaware.

In the final stage, we take the basket of critical skill and assessment them against a list of metrics. We developed a list of 21 metrics that will allow an analyst to determine critical vulnerabilities in a nation's workforce. Table B.4 presents these measures. We analyze the future workforce by examining the nation's education system, current workforce, and the DIB's labor demands. By understating the capabilities of the current workforce; the ability of the educational system, both colligate and vocational, to augment those capabilities in the future; and the DIB's ability to employee skilled labor, we gain an understanding of both the size and drivers of skill gaps. This in turn tells us both how the nation might try to mitigate these gaps and how long that mitigation may take.

As stated, the above process will output an explanation of why certain critical gaps exist within the target nation's DIB and how long those gaps may persist and how those gaps may impact the DIBs ability to meet national strategic priorities.

By focusing our analysis on only those cases that have been identified by the target nation, we limit our ability to identify previously unknown vulnerabilities. This limitation could be solved by conducting interviews to create the final basket of critical skills based on subject-matter expert feedback, but this can require months of planning and execution, not to mention analyzing the output data. Such a time commitment was not possible for this study, but we encourage future studies to employ such a method if time and funding permits.

One of the reasons our approach focuses on identifiable workforce vulnerabilities is that the overall quality of a workforce is nearly impossible to quantify. This is especially true for traits such as innovation, creativity, dedication, and productivity of workforce personnel. We can collect some quantitative indicators, such as levels of education and experience, but it is difficult to consider the importance of each indicator against the others. Our methodology is well suited to tracking careers for skills for which there are clear paths for training and accreditation.

Focusing on human-centric problems may overlook other factors that affect the workforce, such as how well it has integrated technology (e.g., automation). These factors were partially addressed for in the prior chapter, but it is important to note that there is overlap here.

Table B.4. Workforce, Labor, and Skills Measures

Category	Measured Concept	Metric	Sources
Education	Higher education	• Mean annual college graduates in field • % student body at top universities in field • # of PhDs produced per year • PhD connection to international field • Number of hosted foreign students in field	• National Science Foundation, *Science & Engineering Indicators 2018* • UNESCO Institute for Statistics database • Nature Index
	Skilled	• Vocational/trader school systems • Mean years training to practice • Master status requirements	• UNESCO Institute for Statistics database
Current workforce	Experience	• Mean years in field • % workforce under 35 • % workforce over 55	• World Bank Economic Indicators • National statistics bureaus
	Expertise	• Skill sophistication • Dominant submarket?	• Sector-specific reports
	Productivity	• Equipment/machines/weapon systems produced • Number of peer-reviewed journals published	• National statistics bureaus
DIB labor demands	Appeal	• Average salary of worker • Public attitudes toward DIB • Perceived quality of life of labor	• International Labour Organization, ILOSTAT database • National statistics bureaus
	Demand	• Number of job vacancies • Average length of job posting • Number of firms in DIB	• Wittgenstein Centre data • OECD.Stat

Our approach also allows policymakers to put skill and labor gaps into the context of another nation's DIB. Workforce gaps do not exist in a bubble. Rather, workforce gaps affect and are affected by other aspects of the DIB. Our method is designed to work in unison with the other evaluation methods described in this report. Thus, policymakers who use our method will gain not only an understanding of gaps within the DIB's workforce but also added context to the findings from the other methodologies. By so doing, policymakers should gain a holistic understanding of the vulnerabilities and strengths of a given DIB.

B.5. Manufacturing

The nature of international trade and longstanding international trading agreements gives rise to formal definitions of *manufacturing* generally accepted by most nations. We adopted those definitions for this study because they link to existing structured data sources for use in analyzing a DIB's manufacturing. Some trading blocs and individual nations use alternative terms and coding systems (such as the North American Industry Classification System [NAICS]), but sectoral "cross-walks" are readily available. *Manufacturing* is often defined as one significant component of the broader term *industry* and typically excludes natural resource extraction. A globally accepted definition used by the UN states that manufacturing is "the physical or chemical transformation of materials, substances, or components into new products. . . . Substantial alteration, renovation or reconstruction of goods is generally considered to be manufacturing."[265]

Another interpretation adds that manufacturing entails power-driven machines and materials-handling equipment, to distinguish it from artisanal activities.[266] Almost every nation that trades or wishes to catalog its own economic activities bundles manufacturing into a discrete number of activities. Three common methods of scoping and coding manufacturing according to primary value-added function are listed in Table B.5. ISIC codes are linked to products, services, or activities described in national statistical annexes with a high degree of reliability.[267]

Table B.5. Common Manufacturing Coding Systems

Standardized Coding System	Typical Manufacturing Codes (Lower to Upper Range)	Primary Users
NAICS (2017)	3100 to 3999	U.S., Canadian, and Mexican manufacturers, government agencies
ISIC Version 4.0 2008 Section C	10 to 33	Global manufacturers, non–North American governments
ISIC Version 3.1 2002 Section D	15 to 37	Global manufacturers, non–North American governments

SOURCES: United Nations, Department of Economic and Social Affairs, Statistics Division, 2002, 2008; NAICS Association, website, undated.

Framework

Not all activities that support manufacturing are considered manufacturing in their own right. Inputs and certain outputs are often treated as distinct from the manufacturing activity itself. The U.S. National Institute of Standards and Technology (NIST) provides a manufacturing process schematic useful for defining manufacturing activities.[268] In the manufacturing model depicted in Figure B.3, manufacturing processes are distinct from inputs and externalities, such as carbon emissions, wastewater, and e-waste. Green boxes indicate an input or externalities outside the manufacturing ecosystem, and red boxes indicate outputs that could be considered a part of manufacturing or directly related to the output of manufacturing. Inputs and outputs—both desirable and undesirable—are immanent to manufacturing activities and their total cost, but it is

[265] United Nations, Department of Economic and Social Affairs, Statistics Division, 2008, p. 85.

[266] United Nations, Department of Economic and Social Affairs, Statistics Division, *International Standard Industrial Classification of All Economic Activities (ISIC)*, Rev 3.1, New York, 2002, p. 69.

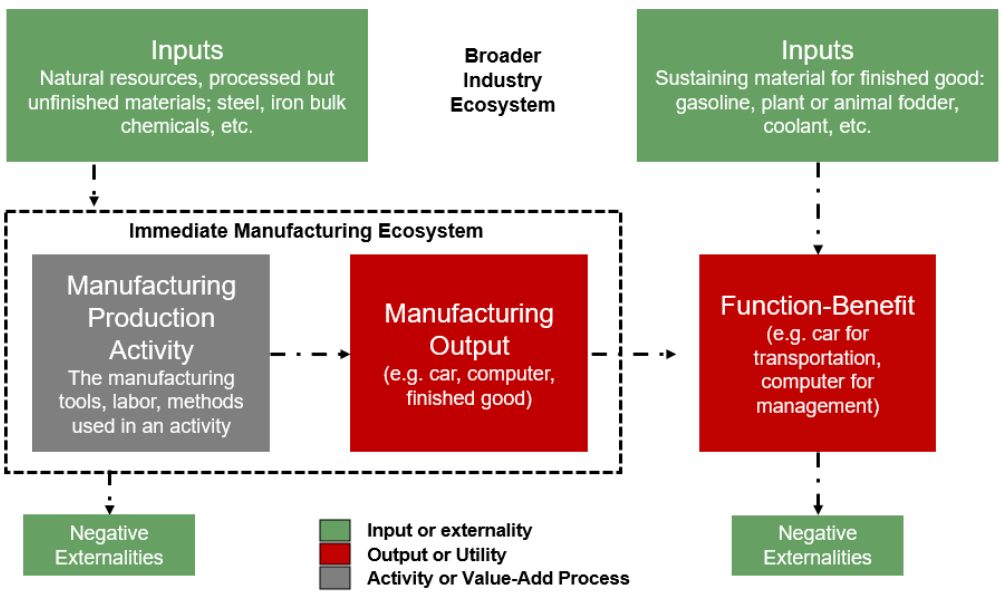
[267] Ulrich Schmoch, Francoise Laville, Pari Patel, and Rainer Frietsch, *Linking Technology Areas to Industrial Sectors: Final Report to the European Commission*, November 2003.

[268] Douglas S. Thomas, *Annual Report on U.S. Manufacturing Industry Statistics: 2020*, Gaithersburg, Md.: National Institute of Standards and Technology, October 2020, p. 5.

important to draw a boundary around a manufacturing system within the broader category of industry. The dashed box that encloses "Manufacturing Production Activity" and "Manufacturing Output" captures the categories and value-added manufacturing outcomes that are commonly captured in NAICS or ISIC tables of data.

Depending on the laws and costs imposed on manufacturing firms generating pollutants or other categories of negative externalities, it may be appropriate to include these items in the manufacturing system; this will depend on the specific country of interest. Knowledge of that nation's system of governance and how manufacturers are regulated and taxed will help inform that choice.

Figure B.3. Manufacturing Process Model Within Broader Industry Ecosystem

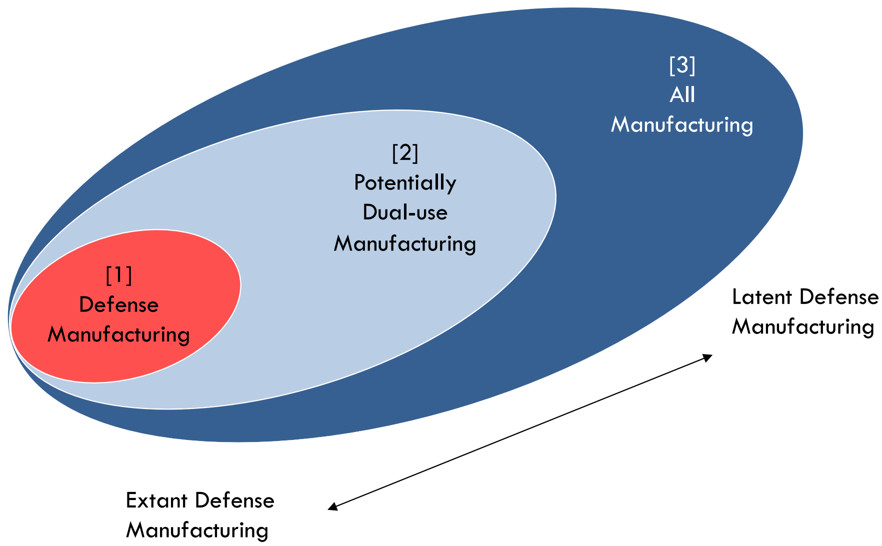


SOURCE: Adapted from Thomas, 2020. Manufacturing ecosystem designation and element examples annotated by the authors.

The DIB portion of the manufacturing ecosystem can be considered along narrow or broad dimensions. A narrow definition could include extant defense manufacturing or manufacturing that already serves defense-related purposes. This narrow category might include commercial arms manufacturers and subcontractors, state or commercial weapon exporters, and commercial firms that may produce products used by both military and civilians. A broader category of the manufacturing DIB could include manufacturing categories that are considered latent DIB: factories that are dual-use in nature and manufacturing that may not be dual-use by design but could conceivably be adopted to support the DIB. The broadest possible dimension of a manufacturing DIB would include all manufacturing as being at the DIB's disposal, perhaps only imaginable under wartime extremes. A qualitative representation of these narrow and more expansive definitions of a manufacturing DIB is shown in Figure B.4.

These general categories of existing (Zone 1) and potentially available (Zone 2) manufacturing DIB capacity will vary in their size and relevance, as every nation's DIB is different. A weakness of this approach is that it requires some subjective judgment on the part of an analyst to determine whether a manufacturing activity should be included or excluded from the DIB. That weakness can be compensated for by thoroughly describing a particular nation's DIB conditions and leveraging the additional economic categories of DIB analysis or insight into the feasibility and likelihood of DIB conversion (Zone 2).

Figure B.4. Extant and Latent DIB Manufacturing Categories



Identifying the dedicated manufacturing DIB for a nation could be as simple as reviewing the manufacturing outputs coded (ISIC, NAICS, etc.) for defense-related products and summing their total to understand the scale of the manufacturing DIB. Depending on the nation, there may also be an approach that requires aggregating defense manufacturing firms' contribution to manufacturing DIB. Aggregating defense firm output as a proxy for manufacturing DIB, depending on the country, may also be a simpler task than summing select manufacturing codes. Admittedly, this task is easier when a nation's defense firms are few and accounting is clear and public—qualities that seem uncommon in many of the world's best-armed nations.

There is no single definition or standard of *dual-use manufacturing*, but in general manufacturing that includes items at military specification (MILSPEC) or under compatible standards for commercial or military application is dual-use.[269] National idiosyncrasies could

[269] Linda Brandt, "Defense Conversion and Dual-Use Technology: The Push Toward Civil-Military Integration," *Policy Studies Journal*, Vol. 22, No. 2, 1994, p. 360.

determine whether classes of manufacturing are already identified as dual-use. Some nations have dedicated programs that clearly specify what is or is not a dual-use manufacturing capability. In cases for which dual-use is subjective, it may be more helpful to default to the subjective exercise of marking manufacturing code categories that appear to be inherently dual-use, such as shipbuilding, large vehicle chassis production, and chemical propellant manufacturing. Table B.6 lists the manufacturing ISIC codes that we included in our analysis.

Table B.6. Breakout of Major Manufacturing Codes (ISIC Rev. 4, 2008, Section C)

ISIC Version 4.0 Manufacturing Code	Associated Product Categories ("Manufacture of . . .")	Select DIB Mentions
10–12	Food, beverages, tobacco	
13–15	Textiles, wearing apparel, leather	
16–17	Wood products, paper products	
18	Printing, recorded media	
19	Manufacture of coke, refined petroleum products	• Most fuels for motor vehicles
20	Chemical products	• 2011 Nuclear reactor fuel elements • 202– Explosives, propellants
21	Pharmaceuticals, medicinal chemical and botanical products	• 2100 Vaccines
22	Rubber and plastics products	
23	Other non-metallic mineral products; glass, ceramics, stone	
24	Basic metals	
25	Fabricated metal products (not machines)	• 2520 Weapons and ammunition
26	Computer, electronic and optical products	
27	Electrical equipment	
28	Machinery and equipment	• 2811 Marine engines
29	Motor vehicles, trailers and semi-trailers	
30	Other transport equipment	• 301 Building of ships, floating structures • 303 Air, spacecraft • 304 Military fighting vehicles
31	Furniture	
32	Other manufacturing	
33	Repair, recycling	

SOURCE: United Nations, Department of Economic and Social Affairs, Statistics Division, 2008.

Estimating the size of the manufacturing ecosystem that could be readily conscripted into the DIB requires subjective judgment to determine what qualifies as compatible. A similar analytical exercise mentioned in the dual-use category could entail identifying manufacturing codes that include production adjacent to military categories. Some subjective judgment would be required to assess the extent to or efficiency by which 100 units of commercial output might apply to the equivalent military output, such that "deflators" or a coefficient could be applied to capture speculative judgments on a nation's commitment to generate DIB output from an originally non-DIB manufacturing source.

Estimating the size of the manufacturing DIB in wartime extremes could entail taking the total manufacturing sector as a component of GDP as the upper limit of total manufacturing that could qualify. Perhaps the only historically relevant example for the United States would be World War II rationing and planning to support the Allied war effort. As previously mentioned, this consideration was outside the scope of this study.

Method

To assess a nation's DIB, this section provides a sequential methodology to

1. establish the total manufacturing output of a nation, typically by assessing manufacturing as an annual aggregate number that contributes to GDP or provided as an annual total of manufacturing-coded output
2. categorize the components and assess the size of the manufacturing DIB
3. establish whether there are additional categories, between dedicated DIB and total manufacturing, that cover cases of manufacturing that could be converted to DIB
4. qualitatively and quantitatively assess strengths and weaknesses of a nation's manufacturing DIB by using an array of manufacturing indices.

Assessing a nation's dedicated manufacturing DIB and potentially available manufacturing DIB does not immediately inform an analyst as to the strength or weakness of a manufacturing DIB. Additional analysis requires examining how that manufacturing DIB scales, utilizes inputs, leverages supplier relationships, and conducts the numerous activities that qualify as manufacturing. A complete assessment of manufacturing DIB weaknesses would require case studies on individual manufactured items (or their associated codes) and their derived benefit. In the micro-case, this is an effective means to understand supply chain vulnerability, product substitution effects, and manufacturing improvisation, also known as process innovation. Barring such exhaustive studies, general macroeconomic data could prove insightful. Table B.7 provides several indicators that, taken together, could provide insight into a nation's manufacturing DIB to assess its strengths and weaknesses. A review of manufacturing strengths and weaknesses could also include edge and nodal analysis relevant to manufacturing supply chains. Manufacturing supply chain vulnerability analysis was beyond the scope of this effort, but relevant metrics could include numerical counts of manufacturing categories that possess single-point-of-failure suppliers and enumeration of node redundancy, among other approaches.[270]

[270] See, for example, Joseph R. Biden Jr., *Executive Order on America's Supply Chains*, Washington, D.C.: The White House, February 24, 2021.

Table B.7. Manufacturing Measures

Category	Measured Concept	Metric	Sources
Manufacturing capacity	Manufacturing scale	• Annualized value of total manufacturing output • Manufacturing as a percentage of GDP	Component of GDP; World Bank and IMF annual reporting includes estimates of manufacturing scale for individual nations.
	Percentage of indigenous manufacturing	• Share of domestic manufacturing component in gross national product (GNP) (as opposed to GDP)	Nation-specific research is typically required. GNP data are less commonly published than GDP data in international sources.
Manufacturing dependency	Sectoral manufacturing trade balance	• Difference between the export and import of manufacturing codes of interest	ISIC reporting available via UN reporting or nation-specific statistical annexes. Code reporting at the three- and four-digit levels of granularity is more likely to capture specific manufacturing products.
	Supply nodes and networks	• Quantitative: edge and nodal analyses • Qualitative: secondary sources on supply bottlenecks and density of supplier networks	Proprietary supply-chain risk surveys and databases are the sources that are most likely to detail supply nodes for any given product.

We provide four areas where manufacturing could be assessed to reveal strengths and vulnerabilities of a DIB. First, manufacturing scale indicates the overall magnitude of manufacturing available to a country, all of which could be available during wartime. This measure also includes the totality of dual-use manufacturing, which is difficult to separate from the civil manufacturing sector. Second, the proportion of a country's manufacturing that is indigenous indicates the country's reliance on foreign firms to achieve domestic manufacturing objectives. Third, the sectoral manufacturing trade balance indicates areas where the country's DIB is capable of meeting specialized manufacturing needs. Fourth, supply nodes and networks indicate manufacturing resilience through an examination of areas where the DIB has single-point suppliers versus a densely webbed economy with multiple supply nodes.

Clear and globally accepted standards for defining *manufacturing* and *manufacturing outputs* exist and can assist in defining a nation's total manufacturing sector. DIB manufacturing can also be represented relatively clearly by enumerating the cohort of manufacturing firms or outputs that serve an immediate military purpose. However, distilling total manufacturing to an intermediate category, such as dual-use manufacturing, is a more difficult and often subjective task. Measuring this intermediate category of defense-adjacent manufacturing requires knowledge of how a good or service conceivably converts into a weapon of war along with nation-specific military requirements.

Categorizing the DIB alone may prove to be an elusive target. Each nation's idiosyncrasies and military posture will determine whether general manufacturing capabilities overlap with dedicated-defense manufacturing. For example, a nation that, by strategy and doctrine, fights local wars without significant armor elements might leverage commercial vehicle pools in ways that a large military with significant armor components might not. In contrast, a nation with sizable elements of tanks and fighting vehicles might have armor requirements too restrictive to be supplemented by commercial vendors. Neither case is necessarily "better" in terms of a DIB. Each nation's specific defense needs could drive an assessment as to whether that domestic manufacturing DIB should include more or less of the general economy.

B.6. Raw Materials

We define *raw materials* as metals and minerals, agriculture, and forestry-based products used for a broad range of applications, including fuels, electronics, and automobile manufacturing. This assessment focuses on metals and minerals for which there is economic value, especially those that support a country's DIB.

The U.S. Strategic and Critical Materials Stock Piling Act defines *strategic and critical materials* as materials that are essential to military, industrial, and civilian needs of the United States during a national emergency and are not found or produced in the United States in sufficient quantities to meet such need.[271] In 2018, the U.S. Department of the Interior classified 35 minerals as critical.[272] In the European Union, "the term 'critical' refers to those raw materials of high importance to the economy in the Union as a whole and whose supply is associated with a high risk."[273] Many country-based assessments for critical raw materials are dependent on whether such materials can be domestically produced.

Framework

In our assessment of how raw materials create strengths or vulnerabilities in a country's DIB, we examined the extent to which raw materials are domestically available to a country versus whether the country must rely on imports. The Herfindahl-Hirschman Index (HHI) is a useful metric that quantifies the concentration risk of a specific raw material for a given market.[274] HHI is calculated by squaring the market share of each firm (or, in the case of minerals, country) providing goods to the market and then summing the resulting numbers and normalizing to 1.

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[271] Public Law 76-117, Strategic and Critical Materials Stock Piling Act of 1939, as amended through Public Law 115-232, National Defense Authorization Act for Fiscal Year 2019, August 13, 2018 (50 U.S. Code §98).

[272] U.S. Department of the Interior, Office of the Secretary, "Final List of Critical Minerals 2018," *Federal Register*, Vol. 83, No. 97, May 18, 2018.

[273] Claudiu C. Pavel and Evangelos Tzimas, "Raw Materials in the European Defence Industry," in *European Commission Joint Research Centre Science for Policy Report*, European Commission, Joint Research Centre, Directorate for Energy, Transport & Climate, Knowledge for Energy Union Unit, 2016.

[274] Orris C. Herfindahl, *Concentration in the US Steel Industry*, doctoral dissertation, Columbia University, New York, 1950. See also Andrew L. Gulley, Nedal T. Nassar, and Sean Xun, "China, the United States, and Competition for Resources That Enable Emerging Technologies," *Proceedings of the National Academy of Sciences*, Vol. 115, No. 16, April 17, 2018, pp. 4111–4115.

One firm or country with 100 percent market share (a monopoly) would have an HHI score of 1. A market consisting of four companies with shares of 50 percent, 30 percent, 15 percent, and 5 percent results in an HHI score of 0.365.[275] The HHI considers the relative size and distribution of the firms in a market. The HHI score approaches zero when a market consists of many firms of relatively equal size. The HHI increases both as the number of firms in the market decreases and as the disparity in size between those firms increases.[276] An HHI score of greater than 0.20 is classified as "concentrated."[277]

World Mining Data is an annual publication created by the Austrian Federal Ministry of Agriculture, Regions and Tourism. Data are collected from questionnaires sent to the National Committees of member countries of the World Mining Congress and to other bodies, such as embassies and foreign trade representatives. The data collected are cross-checked with other official mining statistics, such as data gathered by the British Geological Survey and the U.S. Geological Survey. The report provides a detailed assessment of 65 minerals for which there is economic value, including providing each mineral's HHI. Production numbers include "mine output" and the output from processing at or near the mines (for instance, the upgrading of ores to concentrates). These numbers do not include strategic reserves or untapped reserves. Those minerals are arranged in five groups and shown in Table B.8. Of those 65 minerals, 40 have an HHI score of greater than 0.20.

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[275] $50^2 + 30^2 + 15^2 + 5^2 = 3{,}650$.

[276] Christian Reichl and M. Schatz, *World Mining Data 2020*, Republic of Australia Federal Ministry of Agriculture, Regions and Tourism, 2020.

[277] Reichl and Schatz, 2020.

Table B.8. Classification of 65 Minerals in *World Mining Data 2020*

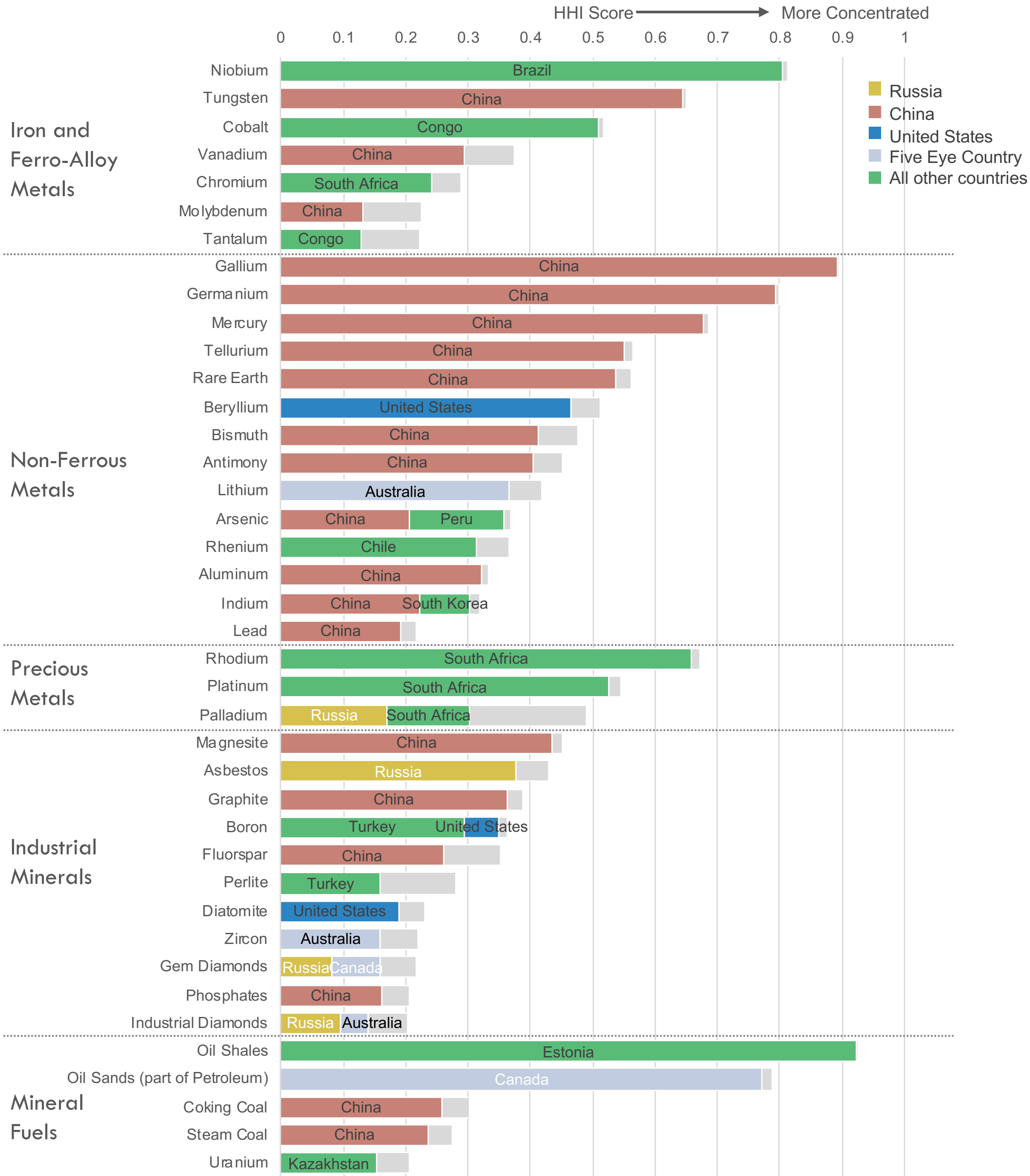
Iron and Ferro-Alloy Metals (11)	Nonferrous Metals (20)	Precious Metals (5)	Industrial Minerals (20)	Mineral Fuels (8)
• Iron • Chromium • Cobalt • Manganese • Molybdenum • Nickel • Niobium • Tantalum • Titanium • Tungsten • Vanadium	• Aluminum • Antimony • Arsenic • Bauxite • Beryllium • Bismuth • Cadmium • Copper • Gallium • Germanium • Indium • Lead • Lithium • Mercury • Rare earth elements (REE) • Rhenium • Selenium • Tellurium • Tin • Zinc	• Gold • Palladium • Platinum • Rhodium • Silver	• Asbestos • Baryte • Bentonite • Boron minerals • Diamond (gem/industrial) • Diatomite • Feldspar • Fluorspar • Graphite • Gypsum and anhydrite • Kaolin (China-clay) • Magnesite • Perlite • Phosphates (including guano) • Potash • Salt • Sulfur • Talc (including steatite and Pyrophyllite) • Vermiculite • Zircon	• Steam coal (including Anthracite and sub-bituminous coal) • Coking coal • Lignite • Natural gas • Crude petroleum • Oil sands • Oil shales • Uranium

SOURCE: *World Mining Data 2020*.

Figure B.5 shows the 40 minerals that have an HHI score greater than 0.20. The bar graph indicates the fraction of market share associated with the United States (illustrated by blue), China and Russia (illustrated by dark pink and gold, respectively), Australia and Canada (illustrated by light blue), and other nations (illustrated by green). It is important to note that this graph reflects current production, not reserves.

A mineral being concentrated in only a handful of countries might restrict access to that mineral based on political alliances rather than market forces. For example, crude petroleum is a critical input to nearly every industry, but the HHI score for petroleum is less than 0.08. This implies a diverse enough market that any country can be assured access to petroleum (although possibly at higher costs). In contrast, about 85 percent of niobium production comes from a single mine in Brazil, with the remaining production split between a second mine in Brazil and a mine in Canada. If Brazil restricts niobium exports to certain countries, those countries might be limited in their access to niobium because there are fewer countries available to replace the shortfall.

Figure B.5. Concentrated Minerals (HHI > 0.20) and Key Producer Countries



SOURCE: RAND analysis of data from *World Mining Data 2020*.

Method

We assessed each of the 40 concentrated minerals for defense applications, while also considering substitutability. Of the 40 minerals that are concentrated, only steam coal, gem diamonds, and mercury are not used in defense applications, because of the lower relative costs of industrial diamonds compared with gem diamonds and the toxicity concerns of mercury.[278] Table B.9 illustrates the defense applications of the remaining 37 minerals. Broad categories of defense applications are provided for brevity, but additional granularity is provided at the end of the references section. Minerals classified as "critical minerals" by the U.S. Department of the Interior in 2018 are indicated with an asterisk.[279]

The minerals within each application are listed in alphabetical order. The applications and minerals at the top of the table have low substitutability, whereas the minerals toward the bottom of the table are more substitutable (although at a potential cost in terms of resources or desired quality). For example, lithium-based alloys display unique characteristics that are essential to serving as a coolant for nuclear reactors, so they are less substitutable than asbestos-based insulation for construction, for which replacements are readily available. Further, while many coatings and alloy compositions provide similar protection from corrosion, substituting minerals for battery (e.g., replacing lithium) or armor (e.g., replacing vanadium) applications would result in significant degradation of performance.

[278] We made a judgment call that generating electricity at steam power plants is not a defense application.

[279] Office of the Secretary of Defense, *Military and Security Developments Involving the People's Republic of China 2018: Annual Report to Congress*, Washington, D.C.: U.S. Department of Defense, 2018.

Table B.9. Concentrated Minerals Used in Defense

Substitutability	Defense Application	Minerals
Less substitutable	Nuclear reactors	Antimony,* bismuth,* boron, graphite,* lithium,* rare earth elements,* uranium,* zirconium*
	Magnets (radar, sonar, flight control, navigation)	Boron, cobalt,* rare earth elements*
	Batteries	Antimony,* cobalt,* graphite,* lead, lithium,* vanadium*
	Armor	Boron, lithium,* tungsten,* vanadium*
	Airframes and jet engines	Beryllium,* chromium,* cobalt,* graphite,* lithium,* magnesite,* niobium,* platinum,* rhenium,* tantalum,* tungsten,* vanadium*
	Photonics (sensors, lasers, light emitting diodes, solar panels, etc.)	Antimony,* arsenic,* beryllium,* gallium,* germanium,* indium,* molybdenum, platinum,* rare earth elements,* rhenium,* rhodium, tellurium,* vanadium,*
	Electronics (microelectronics, assemblies, etc.)	Antimony,* arsenic,* aluminum,* beryllium,* boron, fluorspar,* gallium,* germanium,* indium,* industrial diamonds, lead, molybdenum, niobium,* palladium,* platinum,* rare earth elements,* rhenium,* rhodium, tantalum,* tellurium,* tungsten,* vanadium*
	Weapons and munitions	Aluminum,* antimony,* beryllium,* magnesite,* perlite, phosphorus, platinum,* rare earth elements,* rhenium,* tantalum,* tungsten,* tellurium,* uranium*
	Vehicles	Aluminum,* magnesite,* palladium,* platinum,* rhodium, vanadium*
Somewhat substitutable	Corrosion resistance	Aluminum,* chromium,* fluorspar,* molybdenum, platinum,* tantalum,* vanadium*
	Petroleum products (fuels, lubricants, petrochemicals, etc.)	Oil sands, oil shales
More substitutable	Construction (concrete, insulation, steel)	Aluminum,* asbestos, coking coal, diatomite, perlite, vanadium,* molybdenum, chromium*

SOURCES: Information summarized in this table was derived from a range of readily available sources, including U.S. government documents, industry publications, and scientific literature.
NOTES: An asterisk indicates that the mineral was classified as “critical” by the Department of the Interior in 2018. Magnesite is a naturally occurring source of magnesium, a critical mineral.

B.7. Conclusions About This Methodology

The methodology presented in this appendix was designed to meet the requirement “to continuously assess domestic and foreign defense industries.”[280] In our literature review, only one other methodology was applied to more than one country, the approach in Lynch et al.’s *Vision on Defence-Related Skills for Europe Today and Tomorrow*, and that was specific to labor forces and skills in EU nations. Other methodologies were designed solely for one country or

[280] Public Law 116-283, 2020, Section 1260C(b).

never applied elsewhere. This report provides a methodology that can be repeated both geographically and temporally.

Table B.10 lists several strengths and limitations of this new methodology. The greatest strength—beyond repeatability—is its applicability across a country's entire DIB. Such a broad analysis provides opportunities to reveal how priorities and trade-offs between defense sectors (e.g., aviation, naval, space) are arrived at and to reveal weaknesses or vulnerabilities across all sectors.

Table B.10. Strengths and Limitations of RAND's DIB Methodology

Strengths	Limitations
• Provides a structured approach that is repeatable across countries. • Provides a comprehensive checklist. Allows the analyst to find distinguishing features within countries. • When looking at different DIBs through the same lens, analysts may be less drawn toward biases or myths about a country. • Emphasizes the ability to see strengths and weaknesses/vulnerabilities. • Does not rely on estimates or forecasts. • Designed to be interpreted and applied by non-PhDs. • Granularity of the methodology reveals areas worthy of further investigation; provides a landscape scan of a DIB. • Can be applied with various types of sources, both primary and secondary, that are available to the user. • Usable for a generalist (a non–regional expert). A single team could apply this methodology to many countries without needing a different country-specific team for each application. • Can be used for a single sector assessment (e.g., aerospace, maritime).	• Not an automated methodology; requires investigation and analysis by the user. • Does not emphasize integration across the six topics. • Granularity does not automatically delve into niche topics; deeper dives would need to augment analysis in sectors of interest. • While the methodology is usable for a generalist, a regional expert would have more insight into the data sources that are the most credible and useful. • Seeking consistent data from country to country may be challenging, particularly for smaller countries that may have less data available. Even government ministries in smaller and closed societies may lack data if they have not been collected.

Because the methodology was designed to be repeatable across countries, it was not designed with the assumption that its users would be deep regional experts in any one country. Therefore, a multidisciplinary government team could use this methodology and augment it with an expert on the country being examined. This regional expert could provide insights into which data sources are most credible for the specific country and could offer language expertise in reviewing primary sources.

A limitation of this methodology is that it is not automated, though neither did we find others that are. Automation of parts of the process might be feasible in the future, but we did not devise such an approach.

We also considered the relative advantages and disadvantages of conducting a DIB-wide examination compared with sector-specific analyses (e.g., aerospace, maritime, cyber, nuclear), and we conclude that the best approach would include both, even if not at the same time and within the same study. A DIB-wide assessment involves an examination of trade-offs, and these trade-offs may not be evident in a sector-specific assessment. China could invest anywhere the senior leadership deems a priority. But such a shift would affect other areas, and a DIB-wide assessment could examine the ramifications of these shifts in priorities and resources. Yet, the DIB-wide view misses narrow, niche topic areas that are not readily visible in country-wide data, such as quantum computing, artificial intelligence, and other emerging technologies. For these topics, deep-dive, sector-specific analyses would be more appropriate.

The difference between a DIB-wide versus sector-specific analysis is the difference between breadth and depth. Each approach has its benefits and disadvantages. A combined approach could be possible, but after completing this study we determined that doing so would require a sufficient commitment of time and resources. Doing so on an ongoing basis, however, may prove less daunting once a baseline, initial compound study of a DIB has been prepared.

Appendix C. Our Study Approach

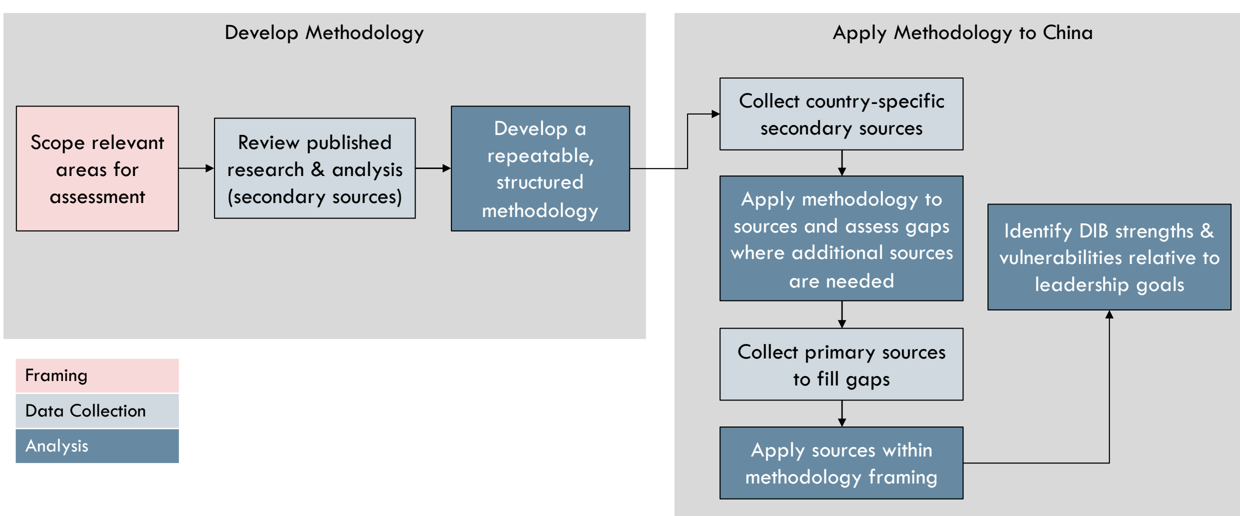
Our Process

Figure C.1 shows our approach to this analysis. We began by framing and identifying relevant areas for assessment, beginning with the FY21 NDAA language and building from there. The six topics included in our methodology are economics; governance and regulations; research, development, and innovation; workforce, labor, and skills; manufacturing; and raw materials. These six topics were initially derived from the FY21 NDAA Section 1260C language (e.g., raw minerals, manufacturing), and additional topics were included based on previous studies of foreign DIBs (e.g., economics).

To meet the constraints of this schedule, we relied heavily on previous studies of foreign DIBs, which prevented us from using data that were not already collected, structured, and published by other sources. Our final methodology was a compilation of the most effective approaches we found.

After scoping the areas for assessment, we conducted a literature review of English-language published sources. These were mostly sources published in academic journals and by research organizations, though we also included a small number of government documents. We used those documents to assess how previous researchers have examined various aspects of a foreign country's economy, DIB, and supporting elements to a DIB, and we used their results to inform our design of a new method for assessing an entire DIB and its vulnerabilities.

Figure C.1. Study Approach



After we created this DIB methodology, we applied it to China as a first test case. We reviewed previous studies conducted on China, and we filled in gaps and updated those analyses with primary literature. This report is the result of documenting our process, findings, and the resulting analytic assessment of the strengths and weaknesses of China's DIB.

Literature Review

We searched English-language journals for secondary sources that included rigorous analysis. The following lists present the databases and search terms that our team used. We started with these databases, in addition to RAND's internal library:

- Academic Search Complete
- Business Source Complete
- Defense Technical Information Center
- eBook Business Collection
- eBook Collection
- EconLit
- Janes
- Military & Government Collection
- Military Database
- PAIS
- Policy File.

We also searched on the websites of these specific organizations whose publications might not have been included in the databases above:

- Center for Strategic and International Studies
- Defense Intelligence Agency
- Organisation for Economic Co-operation and Development
- Tai Ming Cheung's Google Scholar site
- World Bank.

We used the following search terms:

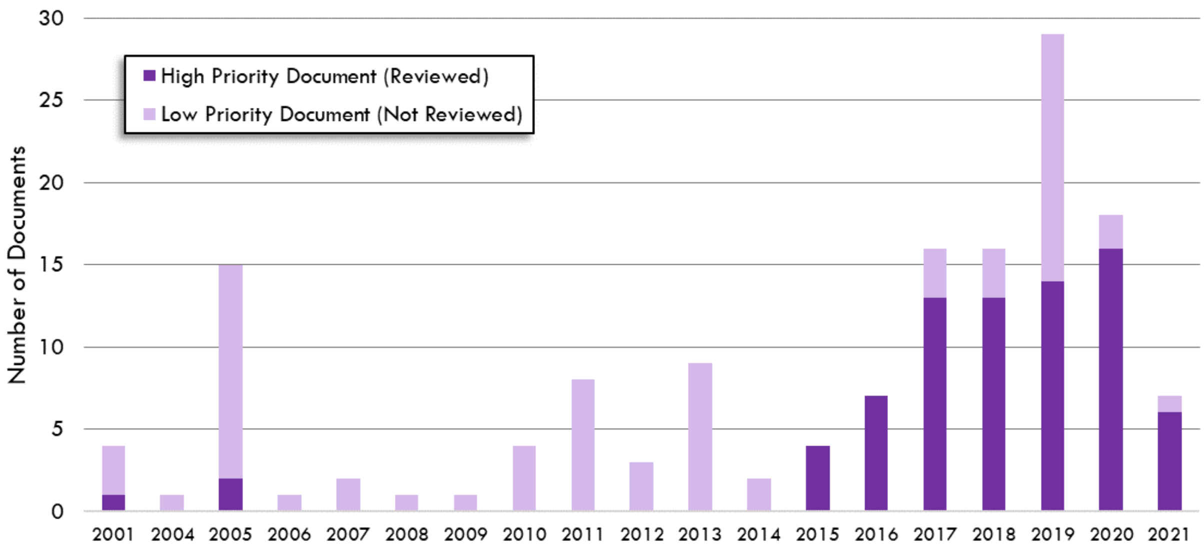
> (China OR Chinese OR Russia* OR Europe* OR Iran* OR Korea* OR German* OR France OR French OR UK OR "United Kingdom" OR Israel*)
>
> AND
>
> aerospace
> defence industr*
> defence sector*
> defense industr*
> defense sector*

industrial base*
military industrial complex
rare earths
rare earth materials
ship building*
shipbuilding.

An asterisk (*) indicates that we captured variations on terms, such as *industry* and *industries*. We searched for all documents since 2001. This search yielded more than 140 documents, which we added to using manual searches, such as through RAND's library of internal publications and other relevant publications that our team was aware of but that did not appear in the results. We ended up with a final list of 148 documents.

Next, we rated these documents based on which ones were high-priority to review. To determine a document's priority, we considered both the timeliness and relevance of the document. We examined all documents published from January 2015 until March 2021, and we omitted documents published during this time period that were not directly relevant to our topic. (Examples of reports that were published during these years but rated not relevant include *The Russian Machine Tool Industry: Prospects for a Turnaround?*, *Brazil's Defense Industry: Challenges and Opportunities*, and *Between Defence Autarky and Dependency: The Dynamics of Turkish Defence Industrialization*.) For documents published before 2015, we looked for examples of methodologies that would be both repeatable and still relevant. The result, shown in Figure C.2, was 76 documents rated as high-priority to review and 72 documents rated as low-priority.

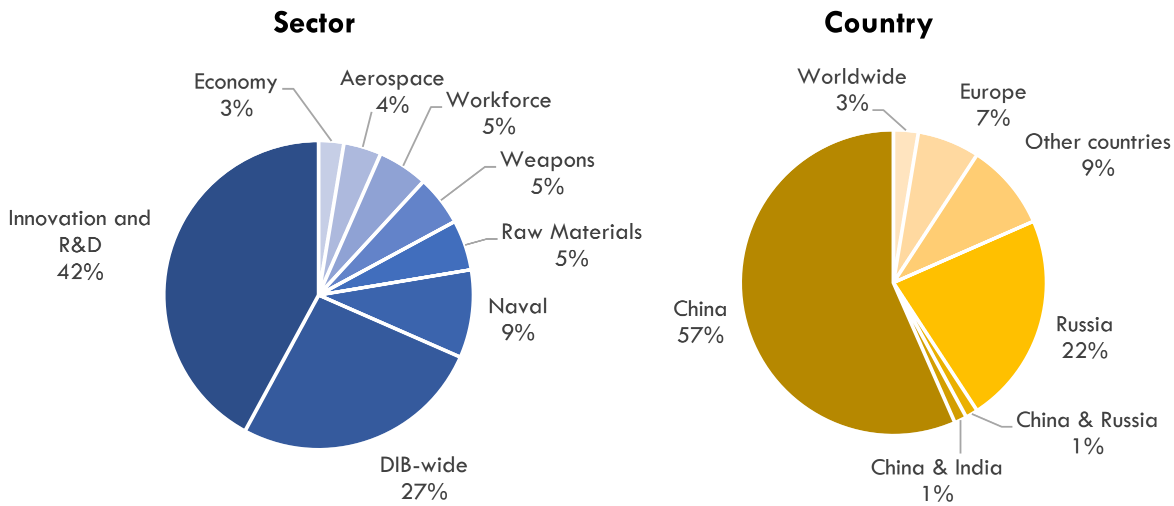
Figure C.2. Literature Reviewed by Year and Priority



NOTE: Total number of documents is 148, of which we identified 76 documents as high-priority and 72 documents as low-priority.

We tagged or labeled each document for the relevant sector and country it applied to. If a document applied widely across the DIB, we labeled it "DIB-wide," and if a document applied globally, we labeled it "Worldwide." All other designations are shown in the two charts in Figure C.3. "Europe" is a catchall term for all European countries other than Russia, and the label "Other countries" includes Australia, India, Iran, Israel, and North Korea.

Figure C.3. Distribution of High-Priority Literature by Sector and Country



NOTES: The data in this figure are based on 76 high-priority documents. In the country chart, "Other countries" includes Australia, India, Iran, Israel, and North Korea.

The high/low-priority rating only indicated whether our team would conduct a detailed review of the document. Once we conducted this review, we assessed whether the document was useful to our study. Thirty-one documents were ruled out because of irrelevance at this stage of our process. The most common reasons why documents were ruled out at this stage were that the methodology employed was not repeatable and that the document did not add to our team's body of knowledge.

For the 45 documents that remained, we used the following list of topics to identify which topics each document addressed:

- labor, workforce, or education
- manufacturing
- raw materials, energy, natural resources
- R&D or innovation
- regulation or governance
- economics
- reliance on U.S. industrial base
- compares to U.S. industrial base.

Many documents addressed multiple items on this list. We generated these categories based on the NDAA language, discussions with the sponsor, and our prior experience assessing DIBs. We used these terms to direct our building of the methodology.

Our team conducted searches on classified computing systems to identify literature and methodologies that we should include. This research was informative in providing us with an understanding of the current state of classified reporting, but it did not add to the body of literature.

Developing a Methodology

We used the literature to develop a series of methods for assessing a DIB across the six topics. Within each of the six topics, we examined the methodologies presented in the literature, which methods were repeatable, and whether publicly available global data sets were available for each method. Even though our first case study was China, we needed to design a methodology that could be conducted for any country and could provide country-to-country comparisons. Therefore, a method for which data existed for China but not for the rest of the world would have been evaluated as unsuitable.

During this stage, while we were considering which global data sets exist for each of the six topics, we also considered several factors for each data set:

- Transparency: Does the data owner clearly explain how the data are collected?
- Analytic rigor: Does the data owner clearly explain the method for any weighting or calculations used in the data set?
- Repeatability: Would these data be updated on a regular enough basis to continue to be useful for future analysts?

As a result of this assessment, several data sets that may have been useful for specific countries or specific niche topics were excluded.

Applying the Methodology to China

As we pivoted to apply our methodology to China, we again began with English-language sources, because of time constraints. Some Chinese publications are published in English, and we included them when available and relevant. Members of our team who are Mandarin-language readers and experts on China's defense industries also collected and reviewed primary sources. These researchers collected Chinese national defense strategies, Chinese-authored self-assessments of the country's DIB, and other documents of relevance to add depth to our analysis and to fill in gaps left by English-language sources.

From our team's previous experience conducting research on Chinese primary sources, we knew that Chinese authors will often publish in English in order to increase the readership audience for their work, but Chinese authors are less likely to publish in English when the topic may be embarrassing to China. Therefore, any studies or analysis originating from China that may discuss weaknesses or vulnerabilities within China's DIB may be unlikely to appear in English.

Abbreviations

AVIC	Aviation Industry Corporation of China
BRI	Belt and Road Initiative
CASC	China Aerospace Science and Technology Corporation
CASIC	China Aerospace Science and Industry Corporation Limited
CCP	Chinese Communist Party
CETC	China Electronics Technology Group Corporation
CNNC	China National Nuclear Corporation
COVID-19	coronavirus disease 2019
CSGC	China South Industries Group Corporation
CSIC	China Shipbuilding Industry Corporation
CSIS	Center for Strategic and International Studies
CSSC	China State Shipbuilding Corporation
DIB	defense industrial base
E	enterprise
EDSP	European Defense Skill Partnerships
FY	fiscal year
FYP	five-year plan
G	government science and technology organization
GDP	gross domestic product
GRI	government research institute
HHI	Herfindahl-Hirschman Index
IC	integrated circuit
IP	intellectual property
ISIC	International Standard Industrial Classification
MCF	military-civil fusion
NAICS	North American Industry Classification System
NDAA	National Defense Authorization Act
NDIS	national defense innovation system
NIS	national innovation systems
NORINCO	China Ordnance Industries Group Corporation Limited, also known as China North Industries Group Corporation Limited
PLA	People's Liberation Army
POE	privately owned enterprise
PRC	People's Republic of China
R	research organization

R&D	research and development
REE	rare earth elements
S&T	science and technology
SIPRI	Stockholm International Peace Research Institute
SOE	state-owned enterprise
STEM	science, technology, engineering, and math
TIV	trend-indicator value
UAV	unmanned aerial vehicle
UN	United Nations
USD	U.S. dollars

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