ESTIMATING FOREIGN MILITARY INVESTMENT

A Case Study in More Accurately Estimating Chinese Military Spending

National Security Report

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Summary

Understanding adversaries' military investment is critical to understanding their decision-making and to formulating sound US national defense strategies and policies. This understanding is complicated, however, by adversaries' lack of transparency about and reporting of their defense spending. Our Johns Hopkins Applied Physics Laboratory (APL) team developed novel approaches to monitor the modernization of adversarial, or red, forces and predict the quality and quantity of their investments. We reviewed the limited research on red force cost estimating efforts to capture best practices and deficiencies and then used these findings to develop a new methodological approach.

Our review of prior red force cost estimating focused primarily on the efforts of two organizations whose estimates are widely cited: the International Institute for Strategic Studies (IISS) and the Stockholm International Peace Research Institute (SIPRI). Their top-down approaches to estimating China's defense spending start with the reported total budget and then account for assumed omissions, such as recent reorganizations of the People's Armed Police Force and Coast Guard. Our analysis of IISS and SIPRI estimating procedures uncovered a potential area for improvement: incorporation of estimates of additional research and development (R&D) expenditures. This category primarily involves factor-based estimation. For example, IISS assumes that only 10 percent of Chinese government research institute budgets are connected to defense efforts, but the defense allocation is probably significantly greater, especially when considering the amount of R&D conducted by universities and industry partners. These additional avenues of defense R&D efforts are enabled by China's centralized economic structure, which relies on state-owned enterprises and a high degree of dedicated military–civil fusion.

We uncovered another opportunity to refine estimates, this one related to currency exchange calculations. Existing methodological approaches to estimating red force investment use market exchange rates (MERs) to compare military investments across nations. Many military goods, however, are not exchanged in the marketplace, and it is not clear that MERs are directly applicable to state-owned enterprises in a centralized economy. Therefore, we devised a unique military cost index to more accurately compare military investments.

Application of this approach to China's spending resulted in a significantly higher cost estimate than other prominent methodologies. Our estimate of the total Chinese military budget for fiscal year 2020 is approximately $500 billion, nearly 100 percent greater than SIPRI's estimate. Moreover, our estimate equates to roughly 66 percent of the US military budget.

These findings are consistent with China's rapid expansion of military capability and suggest that the United States and China may be on more equal footing in terms of military defense spending than other estimates suggest.

Introduction

Understanding adversaries' military investment is critical to understanding their decision-making and to formulating sound US national defense strategies and policies. This understanding is complicated, however, by adversaries' lack of transparency about and reporting of their defense spending. For example, China releases only top-line defense budget figures with little detail on asset allocation. The United States, by comparison, routinely publicly releases detailed defense budget data including both numerical funding levels and narrative descriptions of individual programs or efforts. Moreover, research by British and European think tanks asserts that China omits key defense expenditures, such as research and development (R&D) funding, from its top-line number.

These omissions, as well as other shortfalls in estimating methodologies, have led to speculation that current appraisals of China's defense spending are grossly underestimated.[1] In the 2022 annual report to Congress on People's Republic of China (PRC) military and security developments, the US Department of Defense (DoD) proffers that China's "actual military-related spending could be significantly higher than its officially announced defense budget." The DoD concedes, however, that "actual PRC military expenses are difficult to calculate, largely due to the PRC's lack of transparency."[2] Former chairman of the Joint Chiefs of Staff General Mark A. Milley made similar statements in testimony to Congress, noting that comparisons of the US defense budget with the budgets of adversaries, such as China and Russia, would be much closer if the data was normalized "to compare apples to apples and oranges to oranges," especially regarding the cost of labor.[3]

The deficiencies in adversary force data have led to recent calls—for example, in the National Defense Authorization Act[4]—for the development of methodologies to compare blue (i.e., friendly) and red (i.e., adversary) force defense spending. Our Johns Hopkins Applied Physics Laboratory (APL) team developed novel estimating approaches to monitor the modernization of adversarial forces and predict the quality and quantity of their investments—information that is vital to shaping opportunities to deter opponents from acting against the interests of the United States.

Study Approach

As a first step, we reviewed the limited research on red force cost estimating efforts to capture best practices and deficiencies. These findings helped us scope our focus and influenced our methodology development. We demonstrated methodological improvements via a use case focusing on China. This use case was an obvious choice for several reasons:

- China's sizable and increasing military footprint
- The country's lack of budget transparency (as reported by Transparency International, which gave China a score of only 1.5 out of 12 points)
- Speculation that current assessments of China's defense spending are significantly underestimated

Our review of literature on prior red force cost estimating focused primarily on the efforts of two organizations whose estimates are widely cited: the International Institute for Strategic Studies (IISS) and the Stockholm International Peace Research

1 Funaiole et al., "China's 2021 Defense Budget"; Bartels, *China's Defense Budget in Context*; and Connolly, *Russian Military Expenditure*.

2 US Department of Defense, *Military and Security Developments*, 148.

3 Quoted in Freedberg, "US Defense Budget Not That Much Bigger."

4 National Defense Authorization Act for Fiscal Year 2021, Pub. L. 116-283, Jan. 1, 2021, 134 Stat. 3388 (2021), § 1299H.

Institute (SIPRI). Their top-down approaches to estimating China's defense spending start with the reported total budget and then account for assumed omissions, including recent reorganizations such as the integration of the People's Armed Police Force and defense-related elements of the Coast Guard.[5]

Analysis of IISS and SIPRI estimating efforts uncovered a potential area for improvement: the incorporation of estimates of additional R&D expenditures. This category primarily involves factor-based estimation. For example, IISS assumes that only 10 percent of Chinese government research institute budgets is directed toward defense efforts.[6] The actual defense allocation is probably significantly greater, especially when considering the amount of R&D conducted by universities and industry partners. These additional avenues of defense R&D efforts account for China's political economic structure, which relies on state-owned enterprises and a high degree of dedicated military–civil fusion.

We uncovered another significant opportunity to refine estimates, this one related to currency exchange calculations. Existing methodological approaches use market exchange rates (MERs) to compare military investments across nations. MERs reflect the rate at which one currency is exchanged for another in the marketplace. Comparative assessments using MERs, however, are most appropriate for tradable goods involving financial flows, such as food, textiles, and consumer electronics, as these financial flows are reflected in a nation's currency exchange calculation. The use of MERs is problematic when comparatively assessing countries' military investment valuations for domestically produced, nontraded goods and services. In fact, a significant portion of a country's gross domestic product (GDP), with services and construction as prominent examples, does not enter into international trade.[7] The prevalence of domestically produced, nontraded goods is probably significant for military production. Expensive and advanced weapon systems may be domestically produced because of national security and intellectual property considerations. Moreover, military labor is a "primary instrument of military power" and a significant cost driver in most nations' defense budgets.[8] Although China is ascending to become a developed world power, developing countries predominantly incur nontraded expenses, principally operating and personnel costs, for their militaries—another reason MERs are probably inadequate for estimating spending.[9] As a result, existing methodological approaches probably underestimate the valuation of Chinese military investment compared with that of the United States because the relatively cheaper Chinese labor rates afford a greater "bang for the buck" in domestic production.

Figure 1 is an economics schematic consisting of two conventional inputs, labor and capital, along the axes. These inputs yield military output over time, as expressed by the arrowed red and blue lines, referred to as output expansion paths (OEPs). All military output plots shown in the figure are notional. The focus of this study is below the dashed horizontal line: establishing a red cost baseline for 2020. Initial plots along the OEPs—Y^1_{blue} and Y^1_{red} current estimates—express conventional wisdom that the United States significantly outspends and outproduces red force countries like China on defense. We proffer that once adjustments are made for economic considerations and reporting omissions, the spending is much closer. This is indicated by the black arrow closing the gap between current estimates and our approach.

[5] Nouwens and Béraud-Sudreau, *Assessing Chinese Defence Spending*; and Tian and Su, *A New Estimate of China's Military Expenditure*.

[6] Nouwens and Béraud-Sudreau, *Assessing Chinese Defence Spending*, 9.

[7] Komiya, "Non-Traded Goods."

[8] Bove and Cavatorta, "Budget Shares in NATO Defence Spending," 287.

[9] Krause, *Arms and the State*.

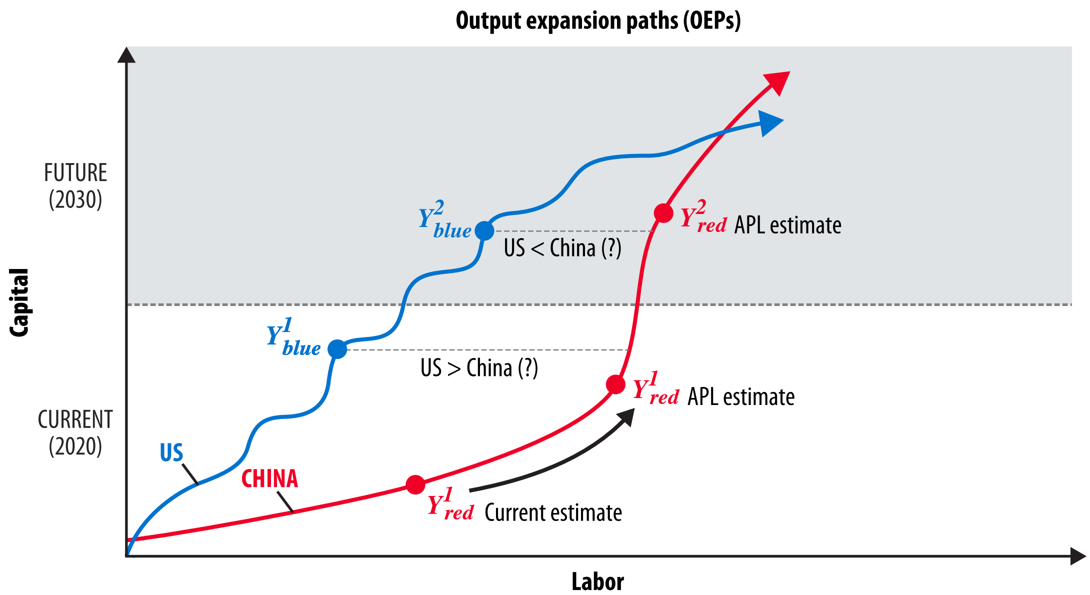

Figure 1. Study Vision

Establishing credible baseline estimates will enable follow-on opportunities to dynamically assess and predict the evolution of red force military investment and its relationship to blue forces. One possible future is represented above the dashed horizontal line in Figure 1, where China's economic growth substitutes more capital for a higher cost of labor, leading to greater output. By comparison, the squiggly blue line reflects business cycles, the booms and busts in the US market economy that might constrain defense spending. By tracking and incorporating changes in China's state-driven economy over time, such as the potential commercialization of the defense industry, this framework will allow analysts to monitor and assess the impacts of adversary modernization efforts.

APL Estimate

China reports top-line military expenditures to the United Nations (UN) annually. The reported fiscal year (FY) 2020 totals are shown in Table 1 in millions of renminbi (RMB) and broken out into three major asset categories: personnel, training and maintenance, and equipment.

To generate our estimate, we adopted the SIPRI and IISS best practice of adding the estimated cost for known omissions to the top-line reported totals. Next, we collected data and separately estimated the R&D funding omitted from existing estimates. We added this amount to the equipment category, which is reported to account primarily for procurement and R&D. Finally, we developed methodologies

Table 1. FY2020 Reported Military Expenditures for China

Country (Currency)	Personnel		Training and Maintenance		Equipment		Total Expenditure (Millions)
	Expenditure (Millions)	%	Expenditure (Millions)	%	Expenditure (Millions)	%	
China (RMB)	383,093	30	428,365	33	480,419	37%	1,291,877

Data source: UN, "Military Expenditures."

to convert the totals in Chinese currency to US dollars (USD) to enable direct comparisons to US defense spending. Subsequent sections detail the R&D estimation and indexing efforts and explain the associated results.

R&D Estimation

According to previous work by Wang,[10] China's official reporting on its defense budget includes R&D funds for military research primarily conducted by People's Liberation Army (PLA) institutes. It excludes defense-related research carried out by research institutes belonging to other government agencies. Furthermore, research has revealed that both defense-related companies and national universities also allocate funds for defense-related R&D. Therefore, accounting for defense R&D efforts at all of these institutes, universities, and companies will enable more accurate estimation of China's total defense R&D investment.

China's National Bureau of Statistics, Ministry of Science and Technology, and Ministry of Finance release annual data on national science and technology (S&T) expenditures, including the total national R&D investment (in RMB). Isolating the exact defense-related R&D spending from the total national R&D expenditure is challenging because China does not release detailed data. However, some information can be inferred from publicly disclosed R&D data—for example, from an online resource called the China Defence Universities Tracker, which was established by the Australian Strategic Policy Institute (ASPI) in 2019. This tracker lists Chinese universities, defense conglomerates, and PLA defense institutes and assesses the likelihood of their collaboration with the Chinese Communist Party and the resulting security risks for other nations. Although there is no publicly available expenditure information for the PLA defense institutes, the assumption is that their R&D spending is captured in the top-line national defense budget published annually. Thus, we focused on estimating the omitted R&D expenditures within each of the three lanes of effort: government agencies, universities, and defense conglomerates.

Government Agencies

For all central government agencies that disclosed information, we obtained 2021 annual fiscal appropriation from China's Ministry of Finance Central Budget and Final Accounts Public Platform. The central government's S&T expenditures, which total 379 billion RMB, are typically allocated to 117 central agencies, including the Chinese Academy of Science, Ministry of Education, and Ministry of National Defense. However, only 102 of these central agencies disclosed their annual central appropriation budgets, with 48 of them reporting S&T expenditures. The central agencies that disclosed S&T expenditures spent approximately 190 billion RMB out of a total 248 billion RMB (76 percent of the total S&T expenditures) on R&D activities, including basic, applied, development, and social science research.

We subtracted these S&T expenditures (248 billion RMB) from the total central government S&T budget (379 billion RMB) to arrive at the remaining S&T expenditures for all non-disclosing agencies (131 billion RMB). These non-disclosing agencies, listed below, are assumed to perform defense-related R&D:

- Ministry of State Security
- State Administration of Science, Technology, and Industry for National Defense
- Ministry of National Defense
- State Cryptography Administration (also known as the State Encryption Management Bureau)
- National Nuclear Safety Administration

[10] Wang, "Estimating China's Defense Expenditure."

- China National Space Administration
- China Atomic Energy Authority
- National Administration of State Secrets Protection

Adhering to SIPRI's R&D estimating approach, we assumed that approximately 90 percent of the non-disclosing central agencies are probably conducting military R&D activities, considering their defense-related missions. Therefore, we estimate that these agencies' defense-related R&D investments total 118 billion RMB. In contrast, SIPRI estimated the same investment to be around 170 billion RMB in 2019. This difference is due to SIPRI not using the actual central appropriation data each year to calculate the funding for non-disclosing agencies. Instead, SIPRI used a baseline number from previous work by Sun and Cao,[11] who computed the R&D estimates by using disclosed appropriation data and applying an annual growth factor derived from the annual increase in Chinese S&T expenditure. This disparity suggests that the central agency R&D expenditure has increased at a slower pace than overall S&T spending.

Universities

To determine Chinese universities' potential defense-related R&D spending, we first examined the annual budgets of universities listed in the ASPI tracker. These include ninety-six civilian universities, seven defense-specialized universities subordinate to China's Ministry of Industry and Information Technology, and two universities subordinate to the Ministry of State Security and the General Office of the Chinese Communist Party. We obtained most of these universities' 2019 R&D expenditures from open-source data published by the Department of Science, Technology, and Informatization in China's Ministry of Education.[12] When R&D expenditures were not available in the open-source data, we used the schools' annual fiscal budgets to estimate them.

Next, we derived a set of factors based on the risk categories assigned in the ASPI tracker to estimate the universities' potential military-related R&D spending from their total R&D budgets. Anecdotal evidence from the ASPI descriptions of each university's R&D efforts indicates that "very high-risk" universities spend approximately half of their R&D budgets on defense-related projects. For example, the Harbin Institute of Technology spent 1.973 billion RMB, or 52 percent of its total research budget, on defense research in 2018. Therefore, we deemed a factor of 0.50 appropriate for very high-risk institutions, and we scaled this factor downward linearly for the remaining risk categories, as shown in Table 2.

Table 2. Factors Based on ASPI Risk Category

Risk Category Assigned by ASPI Tracker	Factor Assigned by APL Team
Very high	0.50
High	0.40
Medium	0.25
Low	0.10

According to the ASPI tracker, there is a very high risk that twenty-four universities focus their R&D efforts on defense. Twenty-three institutions are classified as high risk, and the remaining fifty-eight fall into the medium- or low-risk categories. Application of the factors from Table 2 to the annual R&D spending of each university results in an estimated approximately 105 billion RMB in total defense-related R&D spending from the 105 universities accounted for in the ASPI tracker.

[11] Sun and Cao, "Central Government R&D Spending in China."

[12] Sina Education, "2019 Chinese University Research Funding Ranking."

Table 3. US University DoD R&D Expenditures

Institution	2022 R&D Expenditures (Thousands USD)	2022 DoD R&D Expenditures (Thousands USD)	DoD R&D Factor of Total (%)
Georgia Institute of Technology	1,231,485	694,431	56.4
Johns Hopkins University	3,420,312	1,476,638	43.2
Utah State University	344,851	131,862	38.2
Pennsylvania State University	1,019,940	274,204	26.9
University of Texas at Austin	845,896	211,424	25.0
Carnegie Mellon University	449,707	111,193	24.7
Colorado State University	456,911	100,464	22.0
Massachusetts Institute of Technology	989,166	135,575	13.7
University of Southern California	1,039,905	122,075	11.7
University of Maryland	1,228,550	130,164	10.6

Because we relied on anecdotal evidence to generate the risk factors, we investigated the level of defense funding for analogous institutions to determine whether the anecdotes are reasonable and sufficient. US universities provide one case. The National Center for Science and Engineering Statistics conducts the Higher Education Research and Development (HERD) Survey, an annual survey of accredited US colleges' and universities' R&D expenditures. The survey organizes data by field of research and source of funds.

We calculated DoD's contribution to overall 2022 R&D expenditures by using several of the HERD Survey results tables.[13] The average DoD R&D factor for all 625 institutions is 8.2 percent. This level is not surprising considering that universities' military R&D expenditures are relatively constrained in the United States as compared with those of China, given its institutional factors and mechanisms. Whereas China's university system is centrally planned and executed, many US universities are for-profit or nonprofit entities. Overall, US universities obtain nearly 40 percent of their R&D funding from internal sources, the business market, and nonprofits. Nonetheless, several of the largest R&D universities have DoD R&D factors that are substantially higher than the overall average (Table 3). In particular, the Georgia Institute of Technology, Johns Hopkins University, and Pennsylvania State University receive billions of dollars in R&D funding, with more than 25 percent sourced from the DoD.

A second relevant analogue is the US Department of Energy (DOE) Office of Science, which is a centrally planned research organization. Of all federal agencies, DOE's Office of Science provides the most funding to national laboratories for basic research in science, technology, engineering, and math fields. The annual DOE Congressional budget requests (2010–2020) delineate research allocations by purpose. Approximately 65 percent of all DOE funding to national laboratories between 2017 and 2023 was for defense purposes; this value is greater than the high-risk value used in this study. In summary, both analogues provide evidence that the derived ASPI risk category values are within a reasonable range for estimating Chinese military R&D allocations.

[13] NCSES, *HERD Survey 2022*.

Defense Conglomerates

The ASPI tracker lists twelve Chinese defense industry conglomerates, of which eleven are funded and directly managed by the State Council. They undertake the prosecution and operations functions of major national defense construction projects, defense R&D, and production. Additionally, they are involved in the development, production, and operation of various weapons and equipment for the PLA. The remaining twelfth company is the Commercial Aircraft Corporation of China (Comac), which is an aviation industry conglomerate that has recently faced accusations of being "owned or controlled" by the PLA.[14] We obtained each conglomerate's annual revenue and R&D spending from its income statement.

By using an approach similar to the one we used to estimate university R&D expenditures, we derived a factor based on the ASPI risk categorization to account for the estimated proportion of R&D effort focused on defense. ASPI bins all the defense conglomerates into the high-risk category. Interviews with several employees of various Chinese defense companies suggest that approximately 30 to 40 percent of defense conglomerates' revenue-generating activities are purely military related, while the remaining activities support civilian applications.[15] However, considering the increased civil–military fusion goal the Chinese Communist Party set for the near future, it is probable that at least half of the civilian applications developed by these companies could also be applicable to military activities, according to another published interview.[16] Consequently, the same factor of 0.5 that was derived for universities in the high-risk category is applicable to the defense conglomerates. Application of this factor results in an estimated approximately 40 billion RMB of defense-related R&D expenditures by these conglomerates.

In summary, our estimate for omitted R&D across the three lanes of effort—government agencies, universities, and defense conglomerates—totals approximately 262 billion RMB.

Military Cost Index Approach

As mentioned at the start of this report, existing methodological approaches to estimating red force investment use MERs to compare military investments across nations. MERs, however, are most appropriate when comparing tradable goods. Instead of using MERs, we applied a military cost index that accounts for the delineation between traded and nontraded military goods.

The military cost index leverages an approach by Robertson,[17] who applies the Törnqvist index to geometrically weight the relative prices for a basket of military goods. This approach is commonly used in the field of economics to measure relative price changes due to the substitution effect. The US Bureau of Labor Statistics, for example, uses a geometric mean formula to estimate consumer and producer price indices: "Consumers can—and do, to some degree—insulate themselves from the impact of higher prices by adjusting their spending to favor relatively lower priced goods or services."[18] Stated another way, when the price for a commodity rises, some consumers will seek out and consume a substitute for that good, which dampens the estimated change in output. The geometric mean fixes the expenditure portion for each good in the basket to reflect the substitution effect, which is potentially very significant for this case study, because China is transitioning from a developing to a fully developed country.

[14] Polek, "U.S. Adds Comac to DOD Sanctions List."

[15] China National Defense Science and Technology Information Center, "Ratio of Military to Civilian Products"; and Shaomin, "Accumulating Abundant Military-Industrial Resources."

[16] Bilibili, "Beijing Military Industry State-Owned Enterprise."

[17] Robertson, "International Comparisons of Real Military Purchasing Power."

[18] Dalton, Greenlees, and Stewart, "Incorporating a Geometric Mean Formula into the CPI," 4.

In economics, the Törnqvist index is applied between two or more entities. For the purposes of this study, the index is estimated between two countries, China and the United States, for the year 2020. The military cost index for the basket of goods is based on the three outlay categories that China reports to the UN: personnel, training and maintenance, and equipment. The general equation is shown in Equations 1 and 2.

$$MCI_{us,c} = p_{us,c}^{\bar{\theta}} m_{us,c}^{\bar{\gamma}} e_{us,c}^{1-\bar{\theta}-\bar{\gamma}} \quad (1)$$

$$\bar{\theta} = \frac{(\theta_{us} + \theta_c)}{2}, \bar{\gamma} = \frac{(\gamma_{us} + \gamma_c)}{2}, 1 - \bar{\theta} - \bar{\gamma}, \quad (2)$$

where $MCI_{us,c}$ is the relative military cost index between country *us*, the United States, and country *c*, China; *p*, *m*, and *e* represent the personnel, training and maintenance, and equipment price shares in the United States relative to China, respectively; $\bar{\theta}$, $\bar{\gamma}$, and $1 - \bar{\theta} - \bar{\gamma}$ reflect the average of the personnel, training and maintenance, and equipment shares of military spending in the United States and China, which again, are fixed constants to account for the substitution effect that is typically observed with relative price changes. Each of the three price shares are estimated as dictated by the characteristics of each category.

Training and Maintenance ($m_{us,c}$)

The training and maintenance price share is estimated based on a purchasing power parity (PPP) exchange rate between the United States and China to account for the assumption that the goods produced in this category are not tradable. PPP is a currency exchange index that calculates the ratio of prices of the same good or service in currencies of different nations. Stated another way, PPP estimates the rate at which the currency of one country would have to be converted to that of another country to buy the same amount of goods and services in each country.

In contrast to MER, PPP accounts for price differences between low- and high-income countries. According to empirical analysis contained in the Penn World Tables,[19] prices in high-income countries are typically higher than those in low-income countries. This observation is known as the Penn effect. A classic example, illustrated in Table 4, is the price of a popular soft drink, which is more expensive to purchase in higher-income countries, such as the United States and European Union countries, than in lower-income countries, such as Russia or Mexico.

Table 4. Example of PPP in Different Countries

Country (Currency)	Cost of Soft Drink	
	Local Currency	USD
Russia (Rubles)	90	1.45
Mexico (Pesos)	10	0.53
European Union (Euros)	1.95	2.14
United States (USD)	2.00	2.00

Data source: Robinhood, "What Is Purchasing Power Parity?"

These real-world findings contradict the law of one price, the economic theory that global competition causes international price convergence. The lack of convergence is attributed to several factors, such as relatively fixed input costs. In relation to this study, the labor and material cost inputs for Chinese military production are probably substantially lower compared with those of the United States, resulting in a lower exchange rate relative to MERs, which reflect frequent fluctuations and currency devaluations. Therefore, PPP is assumed to be an improved exchange rate option, given that training and maintenance comprises relatively fixed wages and customized material input costs. As a result, the training and maintenance output costs are probably closer between the two countries of interest than conventionally assumed.

[19] UC Davis, "Penn World Tables."

The PPP rates are provided by the World Bank[20] and represent the exchange rate for GDP, which includes goods and services representative of the entire economy. The PPP exchange rate between the United States and China is approximately 4.18, as compared with the higher MER of 6.9.

Personnel ($p_{us,c}$)

To account for the per-unit labor cost differences between the United States and China, we used a PPP-like index to estimate the personnel price share. Specifically, a skill-adjusted wage ratio is calculated based on Robertson[21] and shown in Equation 3.

$$(p_{n,us}/p_{n,c}) = (\widehat{p_{n,us}}/(\widehat{p_{n,c}})/(h_{us}/h_c). \quad (3)$$

The skill-adjusted wage ratio between the United States and China is estimated as the ratio of nominal labor compensation between the two countries $(\widehat{p_{n,us}}/\widehat{p_{n,c}})$, which is then divided by a human capital index (HCI) (h_{us}/h_c).

To account for the scope of labor's factor output, nominal labor compensation is calculated as the wage share for a country multiplied by GDP for a country. The GDP is a measure of total value or output, and the wage share is a factor of the total compensation that goes to labor. Thus, the nominal labor compensation measures the relative value of labor. The wage share is provided by the Penn World Tables, and the GDP data is provided by the World Bank. Data from 2020 was used in the calculation.

The HCI is applied to account for different skill sets between countries. A high-quality measure of a nation's stock of skills, knowledge, and personality traits to produce military goods and services is not available. As a proxy, the Penn World Tables provide the calculation for the HCI values, which depends on a years-of-schooling calculation[22] and a Mincer equation that estimates the rate of return for each additional year of schooling.[23] The HCI between the United States and China is approximately 1.4, which connotes that effective units of labor are relatively higher in the United States, but not by as much when comparing the United States with other lower-wage countries. The overall personnel price share, $(p_{us,c})$, is approximately 1.87, which signifies that China possesses a relatively cheaper workforce than when estimating using the significantly larger MER value of 6.9. This cheaper workforce connotes a higher valuation of Chinese military investment when compared with US defense spending.

Equipment ($e_{us,c}$)

This study incorporates a hybrid exchange rate for equipment costs, where a weighted PPP and MER index is developed based on the underlying set of equipment goods. A hybrid exchange rate is used because equipment spending involves both traded and nontraded goods and services. At the top level, China's equipment category is composed primarily of R&D and procurement items. China does not disclose most of its R&D investments, so the US defense budget is used as a proxy to determine an R&D factor, roughly equal to 35 percent, which is estimated based on the FY2020 estimate of the Total National Defense (Function 050) and sourced from the DoD's National Defense Budget Estimates[24] and the Office of Management and Budget's Analytical Perspectives tables.[25] This factor is applied against the total equipment cost to extract the R&D value. Note that this total equipment cost includes estimates for the omitted R&D funding detailed earlier. In other words, the R&D portion of the equipment

20 World Bank, "PPP Conversion Factor."

21 Robertson, "International Comparisons of Real Military Purchasing Power."

22 Barro and Lee, "A New Data Set of Educational Attainment."

23 Patrinos, "Estimating the Return to Schooling Using the Mincer Equation."

24 USD (Comptroller), "DoD Budget Request."

25 White House, "Analytical Perspectives."

category equals 35 percent of China's reported equipment cost plus the estimate of the omitted R&D cost. The remaining amount is assumed to represent procurement. This study assumes that the majority of R&D efforts are nontraded because of intellectual property, national security, and nascent technology considerations. As a result, the same PPP exchange index used for training and maintenance is applied to R&D expenditures.

The procurement costs are further decomposed into traded and nontraded assets. A MER is applied to traded assets, whereas a PPP rate is applied to nontraded assets. The decomposition is informed by Chinese arms trades. SIPRI documents the transfers of major weapons among nations over time.[26] For this study, we examined China's importation of major weapons between 2000 and 2021. Helicopters, construction equipment, ammunition, tactical missiles, and combat aircraft are examples of imported weapon systems.

We originally attempted to break out traded versus nontraded assets based on source data on China—for example, by using the IISS Force Structure reports.[27] Estimates of tradable goods, quantity procurements, and total procurement are known, but the lack of per-unit prices precludes this disaggregation calculation. Therefore, we used the 2020 US defense procurement budget request as a proxy. This proxy data set is limited, however, because the per-unit prices and quantities for US production may deviate, possibly significantly, from those for China. A follow-on research action is to develop a bottom-up approach to simulate Chinese per-unit pricing and combine this information with the IISS Force Structure and top-level budget requests.

Based on US procurement budget artifacts coupled with the binning of Chinese procurement assets into two categories, tradable and nontradable, the percent of tradable procurement cost is approximately 35 percent, and the remaining nontradable factor is approximately 65 percent. When combined with the R&D costs, the weighted factor for the tradable MER exchange rate is 22 percent, and the weighted factor for the nontradable PPP exchange rate is 78 percent. These factors contribute to the calculation of a hybrid exchange rate equaling 4.78. When compared with the larger MER value of 6.9, this hybrid exchange rate indicates that China is achieving a greater "bang for the buck" in domestic production. As a result, existing methodological approaches probably underestimate the comparative valuation of Chinese military investment relative to the United States because the relatively cheaper Chinese labor rates afford a greater "bang for the buck" in domestic production.

Cost Shares ($\bar{\theta}$, $\bar{\gamma}$, and $1 - \bar{\theta} - \bar{\gamma}$)

We derived the cost shares for the personnel, training and maintenance, and equipment categories from the reported defense budgets for China and the United States and made adjustments for missing scope. As discussed previously, China's military budget is provided by the 2020 UN report on military expenditures.[28] We modified this budget to account for the SIPRI estimates for known omissions as well as this study's analysis of defense R&D. Inclusion of the omitted R&D for government agencies, universities, and state-owned enterprises, which totals approximately 262 billion RMB, is the primary driver for the significant expansion to the share of the equipment category.

The FY2020 Total National Defense (Function 050) estimate, available from the DoD's National Defense Budget estimates and the Office of Management and Budget's Analytic Perspectives tables, serves as the data source for the US military expenditures. The National Defense Function includes DoD military efforts, atomic energy activities, and defense-related activities. These investments are

26 SIPRI, Arms Transfers Database.

27 IISS, Military Balance+ Database.

28 UN, "Military Expenditures."

Table 5. Cost Shares

Country (Currency)	Personnel		Training and Maintenance		Equipment		Total Expenditure (Millions)
	Expenditure (Millions)	θ (%)	Expenditure (Millions)	$\bar{\gamma}$ (%)	Expenditure (Millions)	$1 - \bar{\theta} - \bar{\gamma}$ (%)	
United States (USD)	157,868	21	317,838	42	281,459	37	757,165
China Raw (RMB)	383,093	30	428,365	33	480,419	37	1,291,877
China Adjusted (RMB)	450,782	25	504,053	28	873,905	48	1,828,740

allocated to China's three major categories to calculate the cost share equation. Personnel includes US total military personnel. Training and maintenance includes DoD operations and maintenance, family housing, military construction, and approximately one-quarter of the energy- and defense-related activities. Equipment includes DoD research, development, test and evaluation, procurement, and approximately three-quarters of the energy- and defense-related activities. Revolving funds, interfund transactions, and trust funds are excluded from the binning, which is tolerable given the low valuation of these items.

The results are displayed in Table 5. The military shares are fairly comparable between the United States and China, with equipment receiving the most funding for China and the other categories representing a roughly even split of the remaining budget.

The military cost index is calculated from the derived exchange rates for training and maintenance, personnel, and equipment as influenced by the cost shares ($\bar{\theta}$, $\bar{\gamma}$, and $1 - \bar{\theta} - \bar{\gamma}$). The resulting index used to convert RMB into USD is 3.67, which is considerably lower than the current MER of 6.9 provided by the World Bank.

Results

This section discusses the outcomes of APL's approach to estimating Chinese defense investments. This research improves on existing methodologies by incorporating the estimation of additional R&D expenditures and developing a credible military cost index to convert Chinese currency to US currency. We constructed our estimate by starting with China's reported figures (in RMB) from the 2020 UN Report on Military Expenditures and adding SIPRI estimates for known omissions such as the People's Armed Police and the Coast Guard. Next, we added the R&D omission estimate and then converted the total estimate from RMB to USD using the military cost index of 3.67.

Figure 2 provides a holistic view of varying estimating efforts for Chinese defense investments, alongside the reported US military budget for FY2020. China's reported budget reflected in USD using MER is the lowest valuation, at roughly $190 billion. IISS published a $193 billion appraisal for China. The SIPRI estimate is approximately $252 billion, which equates to about 33 percent of the US military budget. Both of these organizations' estimates are larger because they included a portion of what they deemed to be omitted costs from China's reported figures. The APL approach results in a significantly higher cost estimate than other prominent methodologies, with a total Chinese military budget estimate of approximately $500 billion. The significantly higher cost is partially due to our modified R&D approach, which accounts for approximately 8 percent of the total $500 billion estimate, and primarily due to our military cost

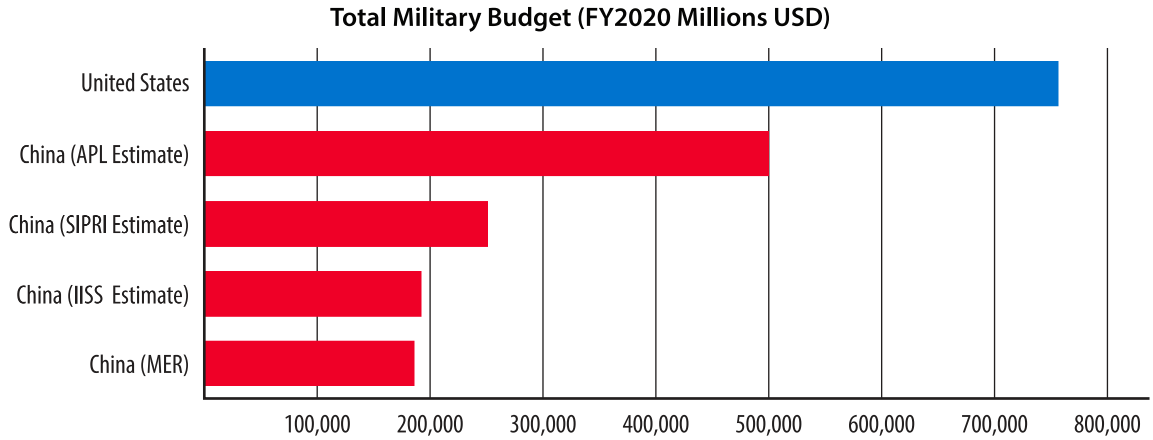

Figure 2. Comparison of Various Estimates of China's Military Spending to the US Military Budget

index approach, which accounts for approximately 55 percent of the total estimate. The remaining 37 percent accounts for the original reported budget for China. The APL estimate equates to roughly 66 percent of the US military budget. These findings reinforce national security concerns over the closing gap in military investments.

Sensitivity Analysis

Considering our significantly higher estimate, it is important to analyze the sensitivity of its primary driver, the military cost index. First, to validate the personnel price share ($p_{us,c}$) of 1.87, we researched pay rates for Chinese military officers and enlisted members and then compared the 2021 rates reported by Chinese media with US military pay rates (Table 6).

The average ratio of Chinese to US military pay across the ranks compiled in Table 6 equals 2.16, which is largely in line with the calculated personnel price share ($p_{us,c}$) of 1.87. Adjusting the APL estimate by using a modified $p_{us,c}$ of 2.16 results in a total cost estimate of $482 billion (which equates to 64 percent of the US military budget) as compared to the original estimate of approximately $500 billion (66 percent of the US military budget). This excursion provides support that the derived personnel price share ($p_{us,c}$) is reasonable.

Another important validation effort involves analyzing the sensitivity of the nontraded asset component of the equipment price share ($e_{us,c}$), which uses the standard PPP rate between China and the United States of 4.18. As explained previously, the nontraded component represents 78 percent of

Table 6. Military Pay Comparison

Rank	Chinese Military Monthly Basic Pay (RMB)	US Military Monthly Basic Pay (USD)	Ratio (China:US)
E-4	5,500	2,330	2.36
E-5	7,400	2,978	2.48
E-6	8,500	3,763	2.26
E-7	12,000	4,562	2.63
E-8	14,000	5,556	2.52
E-9	16,000	6,612	2.42
O-1	8,500	3,395	2.50
O-3	10,000	5,523	1.81
O-5	12,000	8,741	1.37
O-6	14,000	11,218	1.25

Data sources: Data on China: Northern Anhui Army, "Amount of Their Salary." Data on the United States: "2021 Active Duty Pay" (www.military.com) salary tables based on average years of service at promotion to grade (Asch, Mattock, and Tong, *Pay Table for Military Personnel*).

the hybrid exchange rate calculation for the equipment price share. To confirm the appropriateness of the 4.18 rate, we researched Chinese cost data for domestically produced force structure assets and compared this with costs for commensurate US force structure. The limited availability of cost data on China's assets constrained this excursion to a small sample size. The results of this analysis are provided in Table 7.

Although the small sample size makes it difficult to draw conclusions, the calculated ratios shown in Table 7 are below the nontraded component of the equipment price share (i.e., the PPP rate) of 4.18. Per the military cost index methodology, a lower rate yields a higher cost result. The APL estimate is significantly greater than other predominant estimates for Chinese military expenditures, but this sensitivity analysis provides supporting evidence for the veracity of the equipment price share cost driver. For example, applying the average of the Table 7 ratios (3.11) results in a total cost estimate of approximately $540 billion (which equates to 71 percent of the US military budget) as compared to the original APL estimate of approximately $500 billion (66 percent of the US military budget). Moreover, applying the lowest ratio in Table 7, 2.15, represents the highest end of the estimation range at approximately $590 billion (which equates to 78 percent of the US military budget). In summary, this analysis provides support that the derived equipment price share ($e_{us,c}$) is not only within a reasonable range but also might lie at the more conservative end of the range.

Finally, analyzing the sensitivity of the underlying estimate scope for each country ensures that the relative magnitudes are comparable. APL's estimate for Chinese military expenditure includes a portion of the Chinese Coast Guard that is dedicated to paramilitary force efforts. The value is based on SIPRI's methodology and includes approximately 50 percent of the total Chinese Coast Guard budget. SIPRI includes military labor, training, and procurement of vessels with firepower. The US Total National Defense (Function 050) includes defense-related activities (Function 054), which ostensibly include military efforts by the Federal Bureau of Investigation, Central Intelligence Agency, and the US Coast Guard. However, the specific scope for the US Coast Guard was not identifiable. Therefore, we conducted a "what-if" excursion to account for military-related US Coast Guard efforts. The FY2020 Department of Homeland Security US Coast Guard budget is $12.2 billion. Military pay, procurement, and overseas contingency operations accounted for $5.98 billion, or 49 percent of the total US Coast Guard budget.

Table 7. Force Structure Cost Comparison

Force Structure Type	Chinese Asset	Base Year*	Unit Cost (Millions RMB)	US Asset	Unit Cost (Millions USD)	Ratio (China:US)
Ship—Destroyer	Type 052DL	2023	4,500	DDG 51	2,100	2.15
Ship—Cruiser	Type 055	2019	7,000	DDG 51	1,790	3.91
Aircraft—Transport	Y-9	2018	350	C-130J	91.3	3.83
Missile—Surface to Air	HQ-9 (battery)	2018	2,480	Patriot (battery)	967	2.56

* The base year is from the Chinese source data for each force structure type.

Data sources: Data on China: Feng, "Type 052D Warships"; Sina Military, "Type 055 10,000-Ton Destroyer"; Shi, Huang, and Li, "Strong Revenue Growth Potential"; and Military Trade Circle, "Hongqi-9 System." Data on the United States: Derived from President's Budget exhibits and Feickert, *PATRIOT Air and Missile Defense System for Ukraine* and converted to relevant base years through inflation adjustments via FMB-6 Naval Cost Division, Joint inflation Calculator (2023).

Adding the additional US Coast Guard estimates nominally reduces the APL estimate for China's defense expenditures from 66 percent to 65 percent of the US military budget.

Study Limitations

Study limitations create significant uncertainty around the cost estimates for the China use case. This uncertainty can be addressed through follow-on studies focused on improving modeling and confirming the soundness of our approaches. Specific limitations are discussed in the following sections.

R&D Estimating Approach

Data limitations across all three R&D lanes of estimation—central government agencies, universities, and defense conglomerates/companies—bias our estimate downward. A portion of the spending by central agencies that disclose their central appropriation budget could potentially be attributed to defense-related R&D activities. However, determining an allocative factor is challenging. For instance, the Chinese Academy of Sciences oversees ninety-nine research organizations, including the Aerospace Information Research Institute, the Institute of Information Engineering, the Shanghai Institute of Applied Physics, and the Institute of Metal Research. It is highly probable that these organizations conduct defense-related studies, but quantifying the portion of their expenses allocated to defense efforts is not possible without better data. Therefore, the amount of defense-related R&D estimated for central agencies is probably underestimated.

China has 1,270 research-based universities, but the ASPI China Defence Universities Tracker considers only 105 of these universities. Although there is no direct evidence that these other 1,100+ universities engage in defense-related R&D, it is possible that their exclusion from the analysis might further contribute to an underestimation.

Finally, the average total R&D expenditures for defense conglomerates (for both civil and military applications) account for only 4.6 percent of the conglomerates' total revenues in 2021. Nevertheless, these conglomerates oversee numerous research institutes and organizations engaged in military-related R&D activities. For example, the China Ordnance Industries Group Corporation oversees the Changchun Equipment Technology Research Institute and the China Ordnance Industry Experimental and Testing Institute, both heavily focused on military weapon system development and testing. However, because these research labs conduct classified work, their R&D expenditures are not disclosed in their parent companies' income statements—a fact that is explicitly stated in some of the statements. Therefore, the total R&D expenditures reflected in these conglomerates' income statements are probably underestimated. Furthermore, the ASPI tracker does not consider more than one hundred defense companies listed on the Shanghai and Shenzhen stock exchanges and the National Equities Exchange and Quotations. As China's civil–military fusion continues to strengthen, more civilian companies are expected to gain capabilities in producing military equipment and systems. Furthermore, the total market valuation of these defense companies with publicly traded shares is estimated to be 2,370 billion RMB, while the estimation for all companies with civil–military production capabilities is approximately 6,570 billion RMB. This threefold difference suggests that China's defense industry probably incurs additional R&D costs that are not accounted for in this study.

Military Cost Index Approach

Several limitations are related to the use of PPP exchange rates in the formulation of the military cost index. PPP rates are provided by international organizations that base their calculations on the goods and services representative of the entire economy. Furthermore, the PPP calculation leveraged for this effort includes no regional variation; if a significant amount of activity is executed in areas with disparate pricing, this could be a limiting factor of the approach. Also, the defense sector wage profiles used for this study reflect wages across the entire economy, which implies a labor market equilibrium. Hollings[29] provides reason to believe that Chinese military salaries, including those of highly ranked officers, are well below market wages. The estimated defense spending is possibly biased downward as a result.

Finally, as previously mentioned, the use of US proxy data to influence the estimation of the composite procurement exchange rate is limited because significant unit-price and force-structure-quantity differences may exist between China and the United States. The use of US proxies contributes to increased uncertainty in the estimates and highlights the need to improve the estimation efforts by incorporating a bottom-up or engineering build-up approach that accounts for China's investments in specific capabilities.

Conclusions and Follow-on Opportunities

We find that Chinese defense budgets are much more significant than previously estimated by leading methodologies. These findings reinforce the need to further understand current and future Chinese military resource allocation. If the results of this study are accurate, the United States is contending with an adversary whose defense spending is much closer to its own. This finding significantly impacts how we view competition between the United States and China.

[29] Hollings, "Why Does China Pay Its Military Generals So Little?"

It is important to note that total budget amount does not always equate to military capability. The United States spends heavily for a highly educated force, especially at the enlisted levels. This may lead to a force that can adapt to changing conditions and accommodate technological change. The United States also spends heavily to operate its force, which leads to high levels of training and military readiness. Furthermore, this study does not account for the value of military output between the United States and China. A recent RAND study of Chinese budgeting processes cites that inefficiencies and waste due to corruption and misuse exhaust funds that could otherwise produce military capability.[30]

An accurate assessment of current Chinese force structure is critical to inform US military investments and account for emergent threats imposed by the Chinese military force. Moreover, an understanding of Chinese resource allocation may facilitate global posture reviews, so that an appropriate number of defense forces are employed in the Indo-Pacific region. Going forward, accurate and credible forecasts of future Chinese force postures will be vital to shaping US strategic investment opportunities and better understanding China's own forecasted resource constraints.

An engineering build-up of China's defense budget is one valuable follow-on effort that may significantly improve the United States' understanding of China's resource allocation. The Center for Strategic and Budgetary Assessments uses a bottom-up estimating process that relies on the relative pricing of US weapon systems as a proxy, given the lack of reliable price signals in Chinese defense spending.

A follow-on effort could seek to improve on the Center for Strategic and Budgetary Assessments approach by applying optimization techniques, such as genetic algorithms or linear programming, to replace relative pricing with absolute estimates

[30] McKernan et al., *Planning, Programming, Budgeting, and Execution*, 30.

of end-item prices. In addition, the follow-on approach could replace a highly cumbersome set of US-based parametric cost estimating relationships and adjusted analogies with a relatively elegant set of constraints to dictate the relationship of prices. The overall estimate resulting from the effort described here could serve as the most important constraint—a budget constraint by appropriation, which is critical to accurately assessing prices.

In general, the follow-on study could create a time-series flow of procurement quantities from reported stocks of Chinese military force structure using the IISS annual Military Balance+[31] and Department of Defense PLA force structure forecasts.[32] US military prices could serve as a starting point for seeking the optimized Chinese end-item prices. Additionally, physical characteristics of Chinese military platforms could inform technical-based pricing constraints.

The creation of constraining rule sets would be the most significant analytic effort for this proposed follow-on study. The constraints would dictate the absolute prices each and every end item may possess. At the top level, the sum of the per-unit end-item price multiplied by the force structure quantity would be set to equal the total appropriated budget. In addition, a relative pricing constraint could be applied where the rank order of end-item pricing is assumed to be analogous to US-based platforms. Moreover, physics-based constraints could be modeled to limit the range of the Chinese end-item prices, given known physical attributes. The approach could leverage preexisting cost estimating relationships based on physical properties such as weight, displacement, and energy per pound. Optimization could then be employed to generate Chinese military asset prices by matching the force structure flow and constrained pricing requirements to the total estimated Chinese military procurement budget. Finally, blue and red force investments could be comparatively assessed, and possible future investment paths for each country could be evaluated.

As a component of this engineering build-up estimating effort, the ASPI Chinese Defense Universities Tracker could be further used in conjunction with data provided by the National Natural Science Foundation of China to identify the details of potential defense-related research activities at each university. For example, the ASPI tracker classifies China's National Defense University as having a very high risk of being engaged in defense-related research. National Natural Science Foundation data shows that the university received funding to conduct research on spacecraft and resonators, which are potentially used for defense applications.

In this manner, R&D activities could be bucketed into capability categories to understand the drivers of Chinese defense R&D and contribute to the goal of improving the robustness and accuracy of red force cost estimating via a bottom-up approach.

[31] IISS, Military Balance+ Database.

[32] US Department of Defense, *Military and Security Developments*.

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