the review of income and wealth

Review of Income and Wealth
Series 68, Number 3, September 2022
DOI: 10.1111/roiw.12536

THE REAL MILITARY BALANCE: INTERNATIONAL COMPARISONS OF DEFENSE SPENDING

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International comparisons of military spending are necessary for monitoring security risks, assessing defense capabilities, and planning defense budgets. Nevertheless, conventional comparisons do not allow for differences in defense sector input prices across countries. I use defense sector budget data to construct a database of military purchasing power parity (PPP) exchange rates for 59 countries. Real military spending in many countries, including Russia and China, is found to significantly exceed conventional estimates based on market exchange rates and GDP-PPP exchange rates. Similarly, the US share of world military spending is substantially diminished.

JEL Codes: C43, F5, H56, O57

Keywords: military spending, defense economics, price indices, purchasing power parity, military-PPP

1. INTRODUCTION

Comparisons of military spending across countries are used to monitor international security risk, plan defense budgets, and evaluate real military capabilities. It is well known that the accuracy of these international comparisons is limited by many factors such as misreporting, secrecy, the treatment of para-military forces, and complexities arising from dual military-civilian research programs (IISS, 2006; O'Hanlon, 2009; Smith, 2009; Perlo-Freeman, 2011). It is less widely appreciated, however, that even greater errors may arise from the routine conversion of military spending into a common currency such as US dollars.

For example, misreporting and classification errors for China are thought to be in the vicinity of 50 percent (Perlo-Freeman, 2014). By comparison, estimates of China's military budget in $US terms differ by over 200 percent depending on which exchange rate is used (Crane *et al.*, 2005). Similarly current estimates of military spending in $US produced by the US Department of State vary by 78 percent for North Korea, 80 percent for Russia, and more than 150 percent for India, depending on the exchange rate that is used (U.S. Department of State, 2018).

Note: I am very grateful to many people including Theo Backhouse, Lucie Bernard-Sudreau, Ugurhan Berkok, Michael Brzoska, Gordon Flake, Bates Gill, Robert Hill, Tim Huxley, Vanessa Julianna, Harsha Mudiyanselage, Richard Patard, Ron Smith, Stephen Smith, Karl Skogstad, Hugh White, Jingdong Yuan, three anonymous referees, and the participants at the 15th Defence and Security Economics Workshop, Ottawa, 2021. An earlier draft of this paper appeared as UWA Economics Department Discussion Paper DP 19.13.

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Conceptually neither market exchange rates (MER), which can be thought as arbitraging the price of traded goods, nor GDP-purchasing power parity (GDP-PPP) exchange rates, which compare average price levels, are the correct exchange rates with which to compare real military spending across countries. The appropriate exchange rate is the ratio of the implicit prices, or unit costs, of defense services across countries—-i.e., a military-PPP exchange rate. Specifically, a military-PPP exchange rate allows one to compare defense budgets in terms of the real quantity of inputs they procure.

Unfortunately the information required to construct a defense sector, or military, PPP exchange rate across countries typically does not exist. Thus the enormous ranges implied by different exchange rate concepts are an important "known unknown" and a significant source of disquiet for government defense agencies.

In this paper, I use cost minimization and index number theory to construct military-PPP exchange rates for 59 countries. This represents the first database of real military spending across countries since Heston and Aten (1993), whose data were from the 1980s.

I find that, in real terms, the US share decreases from over 40 percent of the global sample to just 25 percent, while the world shares of India and Russia increase significantly. Therefore, although it is commonly reported that the US's defense budget is larger than the next eight countries combined, I find that it is smaller than the next two largest countries—combined. Likewise, the real purchasing power of military spending is shown to be far higher in low- and middle-income countries relative to OECD countries.

The results also show that GDP-PPP exchange rates understate real military spending in most countries relative to the USA. For example, I find that real military purchasing power is 11 percent higher than the level implied by GDP-PPP exchange rates in India, 28 percent higher in Russia, 52 percent higher in Ukraine, 69 percent higher in Indonesia, and around 200 percent higher in Peru and Mexico. I show further that GDP-PPP exchange rates tend to understate relative military purchasing power by more in countries where there are low wages, although there are also important exceptions, including India. Given the importance of accurate data for defense budget planning and strategic analysis, the results thus suggest that more attention to the development of military-PPP exchange rates is warranted.

The paper is organized as follows. Section 2 provides a brief overview of the problem and relevant literature. The theoretical and data issues are set out in Section 3. Sections 4 and 5 present the main results and some sensitivity checks. Section 6 provides some additional context for the results, and Section 7 concludes.

2. Exchange Rates and Real Military Spending

The standard method for comparing military spending across countries is to convert spending in local currency to a common currency, typically US dollars, using MERs (U.S. Department of Defense, 2011; Crane *et al.*, 2005; IISS, 2012; SIPRI, 2012). Because prices for non-traded goods are cheaper in lower-income countries, MERs generally understate actual currency purchasing power in these countries—which is known as the "Penn effect" (Kravis *et al.*, 1975; Summers *et al.*, 1980). To the extent that defense sector spending involves the procurement of non-traded goods and services, such as construction, housing, and salaries, the Penn effect implies that converting nominal military spending to US dollars at MERs may understate military purchasing power (U.S. Department of Defense, 2011; IISS, 2012).

This exchange rate problem is ubiquitous in international comparisons of GDP and standards of living. The literature on international comparisons of real GDP and real welfare addresses the issue by constructing economy-wide PPP exchange rates (Diewert, 2010; Heston, 2013; Feenstra *et al.*, 2015). Given their widespread availability, military spending abstracts, such as IISS's *The Military Balance*, and the US Department of State's *World Military Expenditures and Arms Transfers* database, *WMEAT*, also report comparisons of military spending across countries using GDP-PPP exchange rates.

Nevertheless, because GDP-PPP or consumer price-PPP exchange rates reflect average economy-wide prices, which may differ substantially from defense sector-specific prices, they are likely to be biased indicators of defense sector purchasing power. Moreover, there is no consensus as to which of these exchange rate concepts—a GDP-PPP exchange rate, a market exchange, or something in between—provides a better approximation to relative defense sector prices. While the "Penn effect" suggests that PPP exchange rates would provide a more accurate measure of military purchasing power than MERs, other studies have highlighted that this cannot be assumed because of the importance of imported components in defense spending such as electronics, arms, and machinery (Crane *et al.*, 2005; Gilboy and Heginbotham, 2012; Frankel, 2014). Therefore, there has been an increasing awareness of the need for a defense sector PPP exchange rate (IISS, 2012, pp. 215–216, SIPRI, 2020; The Economist, 2021).

Attempts to compute military-PPP exchange rates include the United Nations (1986), Fontanel (1986), and Cars and Fontanel (1987). The approach in these studies was to collect information on military input prices in cooperating countries. This data requirement, however, is impractical for more than a handful of countries that are able and/or willing to share sensitive data. Heston and Aten (1993) aimed to extend the analysis to 134 countries by econometric extrapolation of the observed military price levels of eight OECD countries that participated in a UN price comparison study of defense sector prices. The use of actual military price data from surveys also meant that the analysis was restricted to data from the 1980s. Since then, there have been no attempts to expand the set of survey countries or construct further defense sector PPP indices across a range of countries.

In the absence of defense sector exchange rates, defense analysts and publishers of defense expenditure abstracts have sometimes taken a pragmatic approach, reporting both GDP-PPP exchange rate estimates of military spending and MER estimates. A few studies have further reported a weighted average of the GDP-PPP exchange rate and the MER, where the weights reflect expedient characteristics such as the labor productivity of the defense sector, the personnel share of spending, or estimates of imports (U.S Department of State, 2018; Crane *et al.*, 2005). These approaches then result in multiple estimates of military spending that, unfortunately, also differ substantially, and little theoretical rationale is given as to why one might choose one number over another, or how the alternatives relate to a concept of a true military price index.

Therefore, while defense sector-specific PPP exchange rates are the correct exchange rates with which to compare real military spending across countries, unfortunately, they do not exist. In what follows I use an approach that is: (i) pragmatic, insofar as it also uses data that are widely available across many countries; (ii) can also be thought of as a weighted average of existing exchange rate concepts, but; (iii) has clear theoretical foundations. The theoretical foundations mean that the results can be more readily interpreted because they have economic meaning. Specifically, the results provide a measure that is a conceptually correct measure of relative unit costs facing the defense sector, conditional on standard assumptions such as constant returns to scale and cost minimization.[1] The resulting data can therefore be interpreted as defense sector PPP exchange rates yielding real military spending levels, under standard economic behavioral assumptions.

3. Measuring Military Purchasing Power

Defense sector output is rarely observed in times of peace and, when it is observed, is not amenable to quantification. Consequently there are no routine comparisons of international military output. Likewise, without a market, there is no observable output price for defense services. International comparisons of defense or military economic activity—e.g., by governments and peace monitoring groups—thus focus on comparisons of defense expenditures, which is a measure of defense sector inputs, not output.

As military spending is measured in local currencies, however, it still needs to be converted into a common currency to ascertain the comparative size of the real resources the local budget commands. This yields the concept of a "real defense budget" or "real military spending." Likewise, we can think of "real military purchasing power" as a measure of relative prices of the input bundles used for defense services.

This broad focus on measuring real military spending, as opposed to output, is also followed here. The resulting measures of real military spending will differ from the output flow of military services, because the latter also depend on non-budget factors such as the command structure, the inter-operability of services, defense force multipliers, public infrastructure, combat readiness, and alliances. Only if these extraneous non-budget factors are similar across countries will similar real defense budgets imply a similar level of real military services or capabilities. The resulting data on real military budgets are nevertheless used for multiple purposes, including as a starting point for more nuanced assessments of military capabilities by defense strategists that consider the various non-budget factors that affect defense sector productivity and the strategic aims of a country's defense spending.

3.1. *Index Numbers*

Comparing real expenditure across countries will therefore amount to comparing the real input bundles used to produce defense services. In evaluating a bundle of input expenditure in two countries, however, we face the standard index

[1]The approach builds on Robertson and Sin (2017) who studied defense sector exchange rates in China relative to the USA.

number problem. In principle, to compare the military spending in two countries, i and k, one could value i's spending in terms of k's prices, or k's input choices at i's prices. These Paasche and Laspeyres alternatives can result in very different valuations of i's spending relative to k. The Paasche–Laspeyres spread arises because the total cost of an input typically does not change proportionally as prices change because of substitution away from more expensive inputs.[2] Therefore, to compare a bundle of military inputs across countries, one must confront the fact that failure to allow for different choices of input mixes across countries will result in substitution bias.

The challenge, therefore, is to find the exchange rate that tells us how much spending would be required in one country to provide the same real military budget, or real bundle of inputs, while also allowing for substitution possibilities between the various inputs.

Specifically, consider the economic decision of a defense planner who allocates expenditure on inputs, x to produce annual defense services, y. The technology is described by the function $y_i = A_i f(x_{1,i}, x_{2,i}, \ldots, x_{n,i})$, where A_i is a productivity parameter representing the extraneous factors that affect the efficiency with which an optimal bundle of defense sector inputs delivers real military services. The function $f(.)$ exhibits constant returns to scale and diminishing returns to each of the n inputs. It will also be convenient to denote real military spending on inputs, as distinct from real output, as $M_i \equiv y_i / A_i = f(x_{1,i}, x_{2,i}, \ldots, x_{n,i})$.

The defense planner's cost minimization problem is then:

$$min\ C_i = p_{1,i}\ x_{1,i} + p_{2,i}\ x_{2,i} + \ldots\ p_{n,i}\ x_{n,i} \mid \overline{y}_i \leq f(x_{1,i},\ x_{2,i}, \ldots, x_{n,i}),$$

where $p_{j,i}$ are the prices of each input $j \in (1, \ldots n)$. The minimum cost function is:

$$C_i = c_i(p_{1,i}, p_{2,i}, \ldots, p_{n,i})\ \overline{M}_i, \tag{1}$$

where $c_i(p_{1,i}, p_{2,i}, \ldots, p_{n,i})$ is the unit cost function for real military expenditure $\overline{M}_i = \overline{y}_i / A_i$.

The ratio of the two unit cost indices in country i and k is:

$$e_{i,k} \equiv \frac{c_i(p_{1,i}, p_{2,i}, \ldots, p_{n,i})}{c_k(p_{1,k}, p_{2,k}, \ldots, p_{n,k})}, \tag{2}$$

and the ratio of real defense sector inputs in each country is:

$$M_i / M_k = (C_i / C_k) / e_{i,k}. \tag{3}$$

The ratio $e_{i,k}$, is a "true" price index or Konüs price index, following Konüs (1939), and therefore is the "true" relative military cost (RMC) exchange rate that converts the nominal spending ratio C_i / C_k into a ratio of real defense sector inputs, M_i / M_k.

[2]For an overview, see Diewert (2004). The issue of substitution bias has its origins in defense economics literature being attributed to a RAND study by Gerschenkron (1951) that aimed to measure Soviet output at the start of the cold war.

If the functional forms of each country's cost function were known, then the true relative cost ratio $e_{i,k}$ could be computed. Nevertheless, without knowing the functional form of the costs function, one can construct a superlative price index to approximate to the true price index (Diewert, 1976; Hill, 2006).

Specifically, consider the Törnqvist index of relative input prices, p_i, in country i relative to k, which is defined as:

$$e_{i,k}^T = \prod_j (p_{j,i}/p_{j,k})^{\theta_j}, \tag{4}$$

where $e_{i,k}^T$ is the Törnqvist approximation to the true value, $e_{i,k}$; $j \in J$ is an element of the set of inputs $J = 1, \ldots, n$, and θ_j is the average input cost share of the two countries for input j, $\theta_j = (\theta_{j,i} + \theta_{j,k})/2$.

The Törnqvist price index is a second-order approximation for any arbitrary cost function and is exact for a translog unit cost function (Diewert, 1976; Allen and Diewert, 1981; Caves *et al.*, 1982b). The following proposition then follows from the preceding discussion and Diewert (1976).

Proposition 1 Suppose the observations from i and k are points on a single minimum unit cost function. Then the Törnqvist index of the unit RMCs is a second-order Taylor series approximation to the true defense sector PPP (RMC-PPP) exchange rate, $e_{i,k}$ that equates real military input spending across countries.

Therefore, we can use empirical estimates of $e_{i,k}^T$ to compute a RMC-PPP (military-PPP) exchange rate that will allow us to convert local currency military budgets in each country into a ratio of real military spending.

Before implementing (4), however, I note, or re-emphasize, some caveats. First in equation (1), the inputs $n_{j,i}$ are homogeneous across countries. In practice, the quality of inputs may differ across countries because of different technologies, particularly different generations of military technology. This means that, in applying (4) to data, the input prices $p_{j,i}$ should be expressed in terms of the price per unit of equivalent quality, or efficiency prices. Therefore, technological differences in inputs can be accommodated, if the input prices are measured as the price per effective unit. This will be important below when we consider the issue of different levels of labor skills' level across countries because differences in skill levels across countries mean that wage costs need to be expressed as wages per efficiency unit of labor.

Second, as discussed above, the defense sector PPP exchange rate, $e_{i,k}$, equates real spending on inputs, or the real budget, M_i, not output, y_i. Differences in non-defense-expenditure factors, such as the command structure, morale, combat readiness, force multipliers, alliances, and civilian infrastructure, will affect real defense service flows for a similar level of input spending. It is important to retain this distinction between real military output and real military spending when considering the results.

Thus we have seen that we can use defense budget data to compare real defense spending across countries and develop a PPP exchange rate for the defense sector that equates the same real defense budget across countries. The Törnqvist RMC index $e^T_{i,k}$ is an approximation to the true RMC-PPP exchange rate $e_{i,k}$. Because it is an arithmetic average of the input price ratios, it allows for demand for an input to change when the prices differ across countries and controls for substitution bias (Gerschenkron, 1951; Hill, 2000; Feenstra *et al*., 2015).

Finally, while the Törnqvist index is a superlative index, it is only one of a family of such indices. As a robustness test, the implications of alternative approaches to approximating $e_{i,k}$ in (2) are explored further below and in Appendix A3.

3.2. *Data*

While detailed input data are unavailable for most countries, standard military budget reporting categorizes military spending into Personnel, Operations, and Equipment spending (Brzoska, 1981, 1995). Therefore, given data on the input cost shares and relative input prices for Personnel, Operations, and Equipment, it is possible to construct $e^T_{i,k}$ using (4) for these three broad inputs.

To calculate the nominal relative prices of personnel, I use data on the number of personnel in the armed forces in each country from the World Bank (2020a). The implicit defense sector wage rate can then be recovered as the total expenditure on personnel, divided by the number of personnel. As discussed in the previous section, we need to adjust this implicit wage rate for differences in labor quality. The implicit defense sector wage rates are therefore converted to wages per efficiency unit of labor, using the Mincerian index of human capital per worker, based on the differences in schooling rates from the Penn World Tables v9.1 (Feenstra *et al*., 2015). Dividing country *i*'s military wage per effective unit by the wage per efficiency unit in country *k* gives the ratio of the defense sector wage rate, per effective worker ≡ $w_{i,k}$.[3]

Price indices for military equipment are not available across countries. Nevertheless, the World Bank International Comparisons Project (ICP) reports the price of machinery and equipment for each country (World Bank, 2020b). Therefore, we use the ICP relative machinery and equipment price as a price index of relative military equipment costs. As ICP data use detailed descriptors to compare items of a similar quality, the prices can also be regarded as price per effective unit. Likewise to the extent that equipment is largely traded, or tradable, differences in quality will be reflected in price differences.

Finally, the category Operations consists of transport, storage, services, and other inputs such as fuels. This category is very eclectic, combining, e.g., various service contractors, construction, infrastructure, transport, and logistics. As such there is no component of ICP data that maps closely onto what this category, and the composition mix of inputs is also likely to differ substantially across countries.

[3]I am grateful to Michael Brzoska and an anonymous referee for suggesting this approach to imputing defense sector wages. A potential limitation is that while I adjust for average labor quality, this does not account for differences in training or selection of defense personnel. Appendix A3.2 discusses the results when using average economy-wide wages. It shows there is little sensitivity for most countries, but using average wages can overstate labor costs when there is conscription or similar implicit subsidies to personnel costs faced by the military sector.

In view of this, I use the ICP GDP-PPP exchange rate as an index of relative operations costs across countries, $\rho_{i,k}$ (World Bank, 2020b).[4]

Given these data, I implement (4) to estimate $e^T_{i,k}$ as:

$$e^T_{i,k} = w^{\theta_w}_{i,k}\,\rho^{\theta_\rho}_{i,k}\,r^{\theta_r}_{i,k}, \tag{5}$$

where $w_{i,k}$, $\rho_{i,k}$, and $r_{i,k}$ are, respectively, the local currency price ratios of Personnel, Operations, and Equipment in i relative to k and θ_w, θ_ρ, and θ_r are the average Personnel, Operations, and Equipment shares of military spending across the two countries.

The cost share data, θ_n, θ_x, and θ_z, are taken from the United Nations Office for Disarmament Affairs who collect spending by three budget categories data for 126 UN Member States (United Nations, 2019). The data are very incomplete, however, and consequently from the 126 member countries the availability of data restricts the analysis to 59 countries. The actual military spending in local currency is taken from SIPRI (2019), and additional data for China are taken from the 2019 China Defence White Paper (State Council Information Office of the People's Republic of China, 2019). Details of these data sources and construction are discussed further in Appendix 5.

I then compute estimates of $e^T_{i,k}$ from equation (5) for 59 countries for the last ICP benchmark year 2017. The 59 countries in the sample cover 86.6 percent of world military spending on a MER basis.[5]

These data are clearly approximate and subject to numerous types of error and mis-measurement. There may, e.g., be differences in personnel selection and training not captured in the skill-adjusted wage data. Likewise, for countries facing sanctions or without procurement allies, military equipment prices may differ from civilian machinery and equipment if they cannot import existing technologies at world prices. There are also broader data quality issues that pervade the literature, e.g., errors to misreporting or a lack of transparency (Smith, 2017). Nevertheless, as having imperfect data is preferable to simply ignore the issue of price differences, the military-PPP approach using input costs provides way forward for deriving better quality comparisons of real defense spending across countries.

4. Results

Table 1 summarizes the results for all 59 countries for the latest ICP benchmark year 2017.[6] Specifically, it reports the resulting implied values of real military spending using both the traditional MER and the military-PPP exchange rate

[4]The impact of using transport services prices is considered in the robustness section below.

[5]Of the missing countries, the largest, in terms of military spending, is Saudi Arabia, which accounts for approximately 4 percent of military spending in MER terms. Other larger countries where data are missing are Israel, Iran, Pakistan, Taiwan, Singapore, Algeria, Oman, Iraq, Kuwait, Thailand, Vietnam, Sudan, and South Africa.

[6]The Penn World Tables Version 10.0 reports GDP-PPP estimates for 2019 (Feenstra *et al.*, 2015). The Supplementary Appendix 4 contains additional results for 2019 based on the PWT GDP-PPP values and 2019 military spending. The general results and conclusions, however, remain the same.

TABLE 1
Countries Ranked by Real Military Expenditure Using Defense Sector PPP Exchange Rates, 2017

Rank	Country	Spending in $USm Military-PPP, $e_{i,k}$	Percent of USA	Rank	Country	Spending in $USm MER, $\mu_{i,k}$	Percent of USA
1	USA	605,803	100.00	1	USA	605,803	100.00
2	China	393,579	64.97	2	China	228,067	37.65
3	India	225,365	37.20	3	Russian Fed.	66,502	10.98
4	Russian Fed.	206,543	34.09	4	India	64,640	10.67
5	Rep. of Korea	82,685	13.65	5	France	60,680	10.02
6	France	80,330	13.26	6	UK	46,602	7.69
7	Brazil	70,383	11.62	7	Germany	45,579	7.52
8	Japan	60,367	9.96	8	Japan	45,358	7.49
9	UK	57,593	9.51	9	Rep. of Korea	39,323	6.49
10	Germany	54,736	9.04	10	Brazil	29,179	4.82
11	Turkey	51,792	8.55	11	Australia	27,685	4.57
12	Italy	46,590	7.69	12	Italy	26,563	4.38
13	Indonesia	39,268	6.48	13	Canada	21,372	3.53
14	Colombia	36,889	6.09	14	Turkey	17,611	2.91
15	Spain	28,397	4.69	15	Spain	16,113	2.66
16	Poland	27,547	4.55	16	Colombia	10,006	1.65
17	Ukraine	24,842	4.10	17	Poland	9977	1.65
18	Mexico	24,140	3.98	18	The Netherlands	9622	1.59
19	Canada	22,002	3.63	19	Indonesia	8168	1.35
20	Australia	21,252	3.51	20	Norway	6463	1.07
21	Philippines	14,283	2.36	21	Mexico	5778	0.95
22	Malaysia	14,213	2.35	22	Sweden	5536	0.91
23	Greece	13,779	2.27	23	Argentina	5456	0.90
24	Chile	13,080	2.16	24	Chile	5363	0.89
25	Romania	12,481	2.06	25	Greece	5116	0.84
26	Argentina	11,056	1.82	26	Switzerland	4628	0.76
27	Peru	10,862	1.79	27	Belgium	4504	0.74
28	The Netherlands	10,621	1.75	28	Denmark	3780	0.62
29	Sweden	7384	1.22	29	Philippines	3755	0.62
30	Norway	6572	1.08	30	Portugal	3662	0.60
31	Kazakhstan	6570	1.08	31	Romania	3643	0.60
32	Portugal	6135	1.01	32	Ukraine	3635	0.60
33	Switzerland	5385	0.89	33	Malaysia	3511	0.58
34	Belgium	5254	0.87	34	Finland	3445	0.57
35	Finland	4916	0.81	35	Austria	3152	0.52
36	Hungary	4808	0.79	36	Peru	2670	0.44
37	Czech Republic	4341	0.72	37	New Zealand	2323	0.38
38	Austria	4081	0.67	38	Czech Republic	2092	0.35
39	Denmark	3913	0.65	39	Hungary	1468	0.24
40	Serbia	3390	0.56	40	Kazakhstan	1388	0.23
41	Bulgaria	3241	0.53	41	Uruguay	1165	0.19
42	Lithuania	2842	0.47	42	Slovakia	1054	0.17
43	Armenia	2824	0.47	43	Ireland	1030	0.17
44	Slovakia	2496	0.41	44	Bulgaria	828	0.14
45	Croatia	2321	0.38	45	Lithuania	816	0.13
46	New Zealand	2306	0.38	46	Serbia	812	0.13
47	Uruguay	2105	0.35	47	Croatia	787	0.13
48	Guatemala	1599	0.26	48	Estonia	540	0.09
49	Ireland	1340	0.22	49	Latvia	512	0.08
50	Cyprus	1200	0.20	50	Slovenia	476	0.08
51	Estonia	1158	0.19	51	Armenia	444	0.07
52	Latvia	1090	0.18	52	Cyprus	359	0.06
53	Slovenia	1010	0.17	53	Senegal	308	0.05
54	Senegal	983	0.16	54	Guatemala	275	0.05
55	Burkina Faso	529	0.09	55	Trin. & Tob.	203	0.03
56	Trin. & Tob.	428	0.07	56	Burkina Faso	192	0.03
57	Rep. of Moldovia	371	0.06	57	Jamaica	144	0.02

(Continues)

TABLE 1 (CONTINUED)

Rank	Country	Spending in $USm Military-PPP, $e_{i,k}$	Percent of USA	Rank	Country	Spending in $USm MER, $\mu_{i,k}$	Percent of USA
58	Jamaica	352	0.06	58	Malta	65	0.01
59	Malta	187	0.03	59	Rep. of Moldovia	31	0.01

Note: $e_{i,k}$ is the military-PPP exchange rate; $\mu_{i,k}$ is the market exchange rate (MER).

TABLE 2
ALTERNATIVE ESTIMATES OF MILITARY SPENDING RELATIVE TO THE USA (MILITARY-PPP)

	Country Code	Country	(1) Base Results—Bilateral Törnqvist	(2) Bilateral Fisher	(3) Multilateral Törnqvist	(4) Multilateral Fisher	(5) Transp. Serv. PPP as rel. Unit Costs for Operations	(6) Unit Wage Costs Based on Economy-wide Average Wages
1	USA	United States	100.0	100.0	100.0	100.0	100.0	100.0
2	CHN	China	65.0	66.8	78.6	78.0	67.2	70.9
3	IND	India	37.2	39.5	44.2	44.3	37.0	44.3
4	RUS	Russian Fed.	34.1	33.5	33.1	32.7	31.5	31.8
5	KOR	Rep. of Korea	13.6	14.2	15.7	15.7	13.6	9.1
6	FRA	France	13.3	13.3	14.7	14.8	11.7	9.8
7	BRA	Brazil	11.6	11.4	11.5	11.3	10.3	11.2
8	JPN	Japan	10.0	10.0	10.1	10.1	8.1	9.3
9	GBR	U.K.	9.5	9.5	9.7	9.6	7.7	9.5
10	DEU	Germany	9.0	9.0	8.4	8.4	7.3	8.9
11	TUR	Turkey	8.5	8.7	9.1	9.1	7.4	6.7
12	ITA	Italy	7.7	7.7	7.0	7.1	7.4	5.7
13	IDN	Indonesia	6.5	6.2	6.9	6.6	6.2	6.1
14	COL	Colombia	6.1	5.5	5.4	5.2	5.8	6.3
15	ESP	Spain	4.7	4.7	4.5	4.5	4.3	3.5
16	POL	Poland	4.5	4.6	4.8	4.8	4.1	3.7
17	UKR	Ukraine	4.1	3.8	4.3	4.2	3.6	3.5
18	MEX	Mexico	4.0	3.8	3.9	3.8	3.6	3.1
19	CAN	Canada	3.6	3.6	3.3	3.3	2.9	4.0
20	AUS	Australia	3.5	3.5	3.1	3.2	3.1	4.2

Note: See Appendix Tables A2–A4 for further details on the derivation of these results.

$M_i/e^T_{i,k}$ from (5). The countries are ranked according to the size of their military spending. For ease of comparison, Table 1 also reports each country's military spending relative to the USA. The full set of results are given in Appendix 1.

It can be seen, first, that military-PPP exchange rates generally imply much higher real military purchasing power than MERs. For example, China's 2017 military budget converted using MERs is US$228 billion. However, in military-PPP terms, it is equivalent to US$393.6 billion.

Therefore, as shown in Table 1, based on MERs, China's military spending in 2017 was 37.65 percent of the USA, but with the military-PPP rate the real

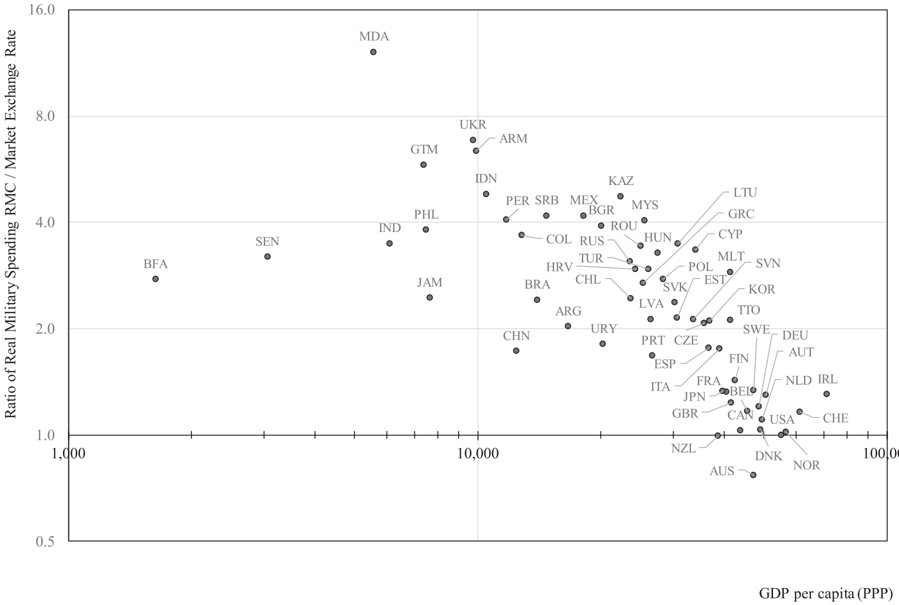


Figure 1. Ratio of Military Purchasing Power Military-PPP/Market Exch. Rate $((C_i/e^T_{i,k})/(C_i/\mu_{i,k}) = \mu_{i,k}/e^T_{i,k})$ and Per Capita GDP

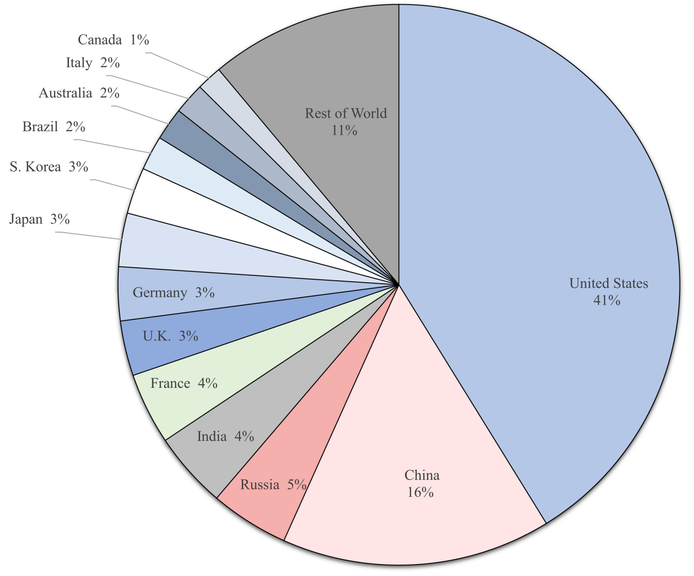
purchasing power is approximately 65 percent of the USA. Likewise, in military-PPP terms, India's defense budget (US\$281 billion) rises from approximately 10.7 to 37 percent of the USA and India becomes the third-largest military in the world, leapfrogging Russia. Russia falls from third to fourth place but nevertheless the size of its budget increases from \$66.5 billion (11 percent of the USA) to \$206 billion (34 percent of the USA).

Second, it can be seen that there is a significant change in the ranking of countries. At the top of the rankings, we have seen India leapfrogs Russia in terms of its real military budget. Similarly, Brazil rises from 10th largest in MER terms to 7th place in military-PPP terms, passing Japan, the UK, and Germany. Other countries with relatively large defense forces that move up the rankings dramatically are Ukraine (15 places), Malaysia (11 places), Peru (9 places), and the Philippines (8 Places).

In contrast, the countries that move down the rankings are the wealthier OECD countries, particularly: Australia (9 places); the Netherlands and Norway (10 places); Denmark (11 places); and Sweden, Switzerland, and Belgium (7 places each). Japan, however, holds its relative position and in so-doing leapfrogs Germany and the UK. On average across countries, defense sector purchasing power is 2.74 times higher than the levels implied when MERs are used.

The difference between the MER estimates of military spending and the military-PPP estimates is in part because of the "Penn effect"—that MERs tend to understate the value of non-traded goods in low wage countries where non-traded goods and services to have lower relative prices.

(i) Military Spending – Market Exchange Rates



(ii) Military Spending – Military-PPP Exchange Rates (RMC)

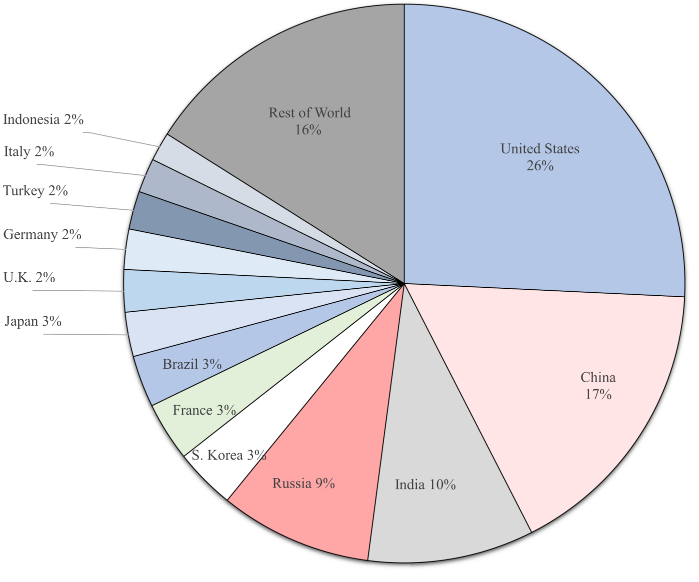


Figure 2. Distribution of Military Spending [Colour figure can be viewed at wileyonlinelibrary.com]

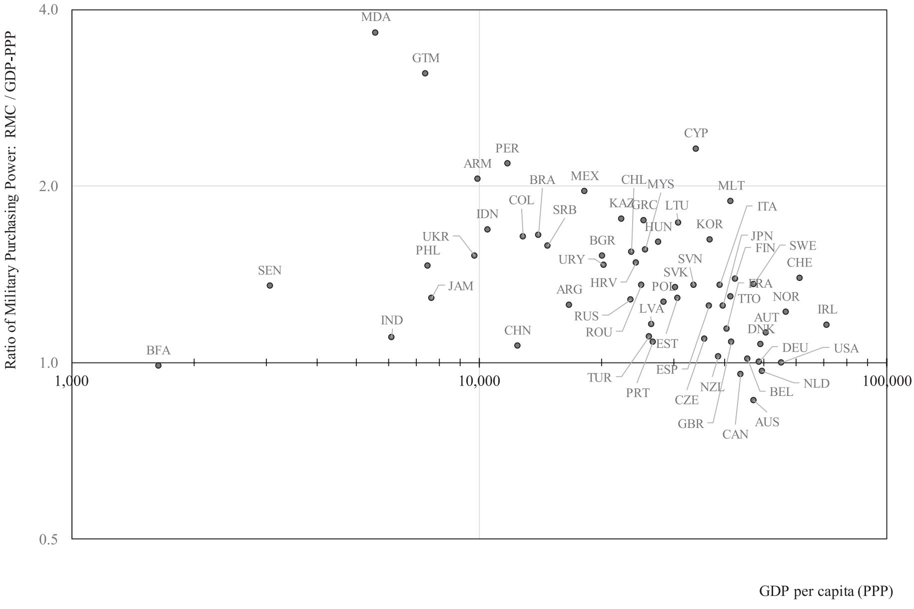


Figure 3. Ratio of Military Purchasing Power Military-PPP/GDP-PPP ($(C_i/e^T_{i,k})/(C_i/\rho_{i,k}) = \rho_{i,k}/e^T_{i,k}$) and Per Capita GDP

The "Penn effect" can be seen in Figure 1, which shows the ratio of the military purchasing power calculated using military-PPP exchange rates, $e^T_{i,k}$, relative to the MER, $\mu_{i,k}$, $(C_i/e^T_{i,k})/(C_i/\mu_{i,k}) = \mu_{i,k}/e^T_{i,k}$ on the vertical axis and per capita GDP on the horizontal axis. The values are plotted with log scales.

The figure shows a negative correlation between the ratio of the MER to the military-PPP exchange rate, $\mu_{i,k}/e^T_{i,k}$, and per capita GDP. This suggests that non-traded goods and services play a very important role in the makeup of defense budgets globally. While purchasing power is 2.74 times higher on average, there is also a very significant range of values across countries with, e.g., Moldovia having a value of 12.1 and Ukraine having a value of 6.8, while countries such as Denmark, Norway, Canada, and New Zealand have ratios close to one, suggesting that defense sector prices are very similar to the USA.

The results also imply significant changes to the global distribution of real military spending by country, which is conventionally viewed as being dominated by the USA. This can be seen in Figure 2, which compares the distribution of world military spending when MERs and military-PPP exchange rates are used, respectively. As noted above, the sample of 59 countries accounts for approximately 86.6 percent of world spending. Panel (i) of Figure 1 shows that using MERs, the USA accounts for 41 percent of this global subsample and, on a MER basis, the US defense budget is larger than the next eight countries combined. As shown in panel (ii), however, on a military-PPP basis the US's defense budget accounts for 26 percent of this global spending. Therefore, in military-PPP terms the US's defense budget is smaller than Russia and China combined. Similarly, in military-PPP terms, China, India, and Russia account for 35 percent of spending in the global subsample. As shown in Appendix 4, the results are also very similar when updated to 2019, with the US's share falling from 45 percent of the global sample based on MERs to 28 percent using military-PPP.[7]

The key result, therefore, is that MERs dramatically understate real purchasing power of military spending in many countries, including Russia, China, and India. On average, the results suggest that MERs understate real purchasing power by a factor of 2.74, but the value can be far larger for low-income countries, where prices differ substantially from US prices.

4.1. *Military Costs and GDP-PPP*

The results have shown that MERs dramatically understate military purchasing power in many countries. An additional important question, therefore, is whether economy-wide GDP-PPP exchange rates—that are presented as alternative estimates of real defense spending across countries in many studies—perform any better.

GDP-PPP exchange rates will also not necessarily be a good indicator of defense sector purchasing power, because they are designed to measure economy-wide average price differences. Whether or not the GDP-PPP exchange rate represents a good proxy for a true defense sector PPP exchange rate will depend on factors such as the capital and labor intensity of defense services relative to the rest of the economy, and use of imported equipment and is likely to differ across countries (Crane *et al*., 2005; Gilboy and Heginbotham, 2012; Frankel, 2014).

The difference between the military-PPP exchange rate, $e_{i,k}$, and the GDP-PPP exchange rates, $\rho_{i,k}$, can be seen on the vertical axis of Figure 3, which reports the ratio of military purchasing power calculated using military-PPP exchange rates relative to GDP-PPP exchange rates, $(C_i/e^T_{i,k})/(C_i/\rho_{i,k}) = \rho_{i,k}/e^T_{i,k}$. The horizontal axis again shows GDP per capita, measured in a log scale, for each country-time observation.

It can be seen that the military-PPP exchange rate estimates of military spending are also significantly larger than the values implied by the GDP-PPP exchange rates with most values lying above unity. For example, the military-PPP estimate of Russia's military budget is 28 percent higher than the GDP-PPP estimate. Moreover, in some countries this difference is very large. For example, in South Korea, Brazil, Colombia, Indonesia, and Greece, the military-PPP estimates of purchasing power are 60–75 percent higher than the GDP-PPP-based estimates. In other countries such as Mexico and Peru, the military cost estimate is around twice the GDP-PPP estimate.[8] Using a simple average across countries, military purchasing power is 44 percent larger than the value implied by ICP GDP-PPP exchange rates.

The results therefore show that the GDP-PPP exchange rates also tend to understate real military budgets in many countries. Again, however, this difference

[7]The 2019 SIPRI data in A5 also incorporate updated definitions of military spending in China, which revise its magnitude down slightly. See Tian and Su (2021) for a discussion of these data revisions.

[8]These ratios are also reported in Table A1 in Appendix 1.

is not uniform across countries with a correlation between per capita GDP and the gap between the two exchange rate concepts. Figure 3 also shows a higher variance in low- and middle-income countries relative to high-income countries.

The data in Figure 3 show that, in most instances, particularly for low-income countries, the military exchange rate implies larger values of real spending than those implied by GDP-PPP exchange rates. That is, as $\rho_{i,k} > e^T_{i,k}$, then $(M_i/M_k)/e^T_{i,k} > (M_i/M_k)/\rho_{i,k}$. For most countries the GDP-PPP exchange rate for machinery and equipment also exceeds the GDP-PPP exchange rate, $r_{i,k} > \rho_{i,k}$.[9] Therefore, from (5), the fact that $\rho_{i,k} > e^T_{i,k}$ reflects the property that, typically, $W^{\theta_w}_{i,k} < 1$.

Consequently countries where real military purchasing power is much higher than the level implied by GDP-PPP exchange rates tend to be those where there is a combination of very low real wages in the defense sector, so that $w_{i,k}$ is small, and where the wage bill occupies a large fraction of the defense budget, so that $\boldsymbol{\Omega}$ is large. In these countries there is a relatively low skill-adjusted defense-sector wage rate, and a relatively labor-intensive defense sector. To the extent that countries with low relative wages are also likely to have more labor-intensive defense sectors, this substitution toward lower cost inputs will magnify the difference between the military-PPP exchange rate and the broad-based GDP-PPP exchange rate. This provides an economic explanation for the pattern observed in Figure 3.

Figure 3 therefore also reveals a useful empirical regularity that may help in understanding when, or what types of countries or situations, the use of GDP-PPP exchange rates is likely to understate real military purchasing power. Specifically, GDP-PPP exchange rates will be a poor approximation to defense sector exchange rates in low wage countries with labor-intensive defense sectors.

Nevertheless, other factors, such as conscription programs and implicit or explicit wage subsidies, also affect relative prices of Personnel. Among the countries with very low implicit defense sector wage rates relative to the economy-wide averages are Armenia, Lithuania, Cyprus, Greece, Korea, and Moldovia, all of which also have some form of conscription, and Hungary which also has service obligations (Central Intelligence Agency, 2020).[10]

It is of interest to compare how these results affect some of the larger countries, especially Russia, China, and India. Russia has a value of $\rho_{i,k}/e^T_{i,k}$=1.28 on the vertical axis in Figure 3—which is a little less than the mean value of 1.44. Nevertheless, this 28 percent difference is clearly very significant given Russia's geopolitical importance. The ratio of military-PPP and GDP-PPP exchange rates, $\rho_{i,k}/e^T_{i,k}$, for India and China, however, is closer to unity, and well below the average for countries in this range of GDP per capita, e.g., compared to the Philippines, Indonesia, and Ukraine.

[9]For this sample, on average the machinery and equipment PPP exchange rate, r, is 9 percent larger than the average GDP-PPP exchange rate. The values of r and ρ for each country can be seen in Table A1.

[10]Table A4 in Appendix 3 reports the ratio of defense sector wages relative to average wages in each country, normalized to the ratio in the USA. Descriptive information on conscription in each country is available in the CIA's *The World Factbook*, Central Intelligence Agency (2020).

There are two factors that explain the fact that $\rho_{i,k}/e^T_{i,k}$ is close to unity for India and China, and lower than other countries in a similar per capita income range. First, both countries spend approximately 40 percent of their military budget on Equipment, which is a far larger procurement share than the average (18 percent) and far higher than, e.g., Indonesia (16 percent) and Ukraine (17 percent), which are at similar per capita income levels. Likewise Russia only spends 15 percent on equipment. In China and India, therefore, the military is relatively capital intensive, despite being countries with very low-cost labor, while in Russia it is relatively labor intensive, according to the UN budget share Data.

Another contributing factor is that military wages in India and China are high relative to the economy-wide average wage. The military to average wage ratio, relative to the USA, is 30 percent higher in China and 60 percent higher in India. This also means that although wages are low in general in these countries—which from Figure 3 typically implies a very small value of the military-PPP exchange rate relative to the GDP-PPP exchange rate—the military wage costs relative to average wages are relatively high. Along with the relatively high share of equipment spending, this increases the value of $e^T_{i,k}$ so that $\rho_{i,k}/e^T_{i,k}$ is small relative to other countries in the same broad per capita income band.

In Russia, however, the ratio of implicit defense sector wages implicit to economy-wide wages is 14 percent lower than the USA, which may again reflect the use of conscription in Russia (CIA 2020). Likewise Russia's Personnel share is also relatively large, accounting for 58 percent of the defense budget. Thus Russian real military spending is significantly higher than implied by GDP-PPP exchange rates because: (i) economy-wide wages are relatively low relative to the USA; (ii) the gap between implicit defense sector wages and economy-wide wages is low when compared with the USA, and (iii) the Russian defense sector is relatively labor intensive.

5. Alternative Index Numbers and Data

To consider the sensitivity of the results to alternative modeling and data assumptions, Table 2 reports real military spending relative to the USA, M_i/M_k, for alternative index number approaches and alterative data. It shows the results for the largest 20 countries ranked in terms of their military budget, in terms of military-PPP, from Table 1.[11]

Column (1) reports the base results from Table (1) again for reference. Column (2) shows the results for the same data when a Fisher price index, $e^F_{i,k}$, is used, which is at least as widely used as the Törnqvist index and has very similar properties.[12] Therefore, the values in Table 2 report $M_i/M_k = (C_i/C_k)/e^F_{i,k}$. It can be seen that

[11]Further details of the method and information for every country is available in Appendix A3.

[12]The Fisher index is defined as $e^F_{i,k} = \left(e^L_{i,k}\ e^P_{i,k}\right)^{\frac{1}{2}}$, where $e^L_{i,k} = \sum_j \theta_{j,k}(p_{j,i}/p_{j,k})$; $e^P_{i,k} = \sum_j \theta_{j,i}(p_{j,k}/p_{j,i})$; for each input price j.

values are very similar to the base values, so that the results are barely affected by the choice between these two most widely used bilateral price indices.

Columns (3) and (4) then report relative real military spending, M_i/M_k, for the multilateral Törnqvist, $M_i/M_k = (C_i/C_k)/e^{MT}_{i,k}$ and multilateral Fisher $M_i/M_k = (C_i/C_k)/e^{MF}_{i,k}$. The multilateral indices have several important advantages over the bilateral index and may well be regarded as the preferred military-PPP exchange rate measure.[13]

For these multilateral price indices, each bilateral exchange rate value depends on the price and quantity information from all countries, not just the relevant pair i and k (Caves *et al.*, 1982a; Fujikawa and Milana, 1996).[14] The net effect is to give greater weight to the labor component of military costs, and this means that the real military spending of China and India tends to increase further. In particular, under the Multilateral Törnqvist and Fisher indices, China's spending becomes 78 percent of the USA's spending, well above the GDP-PPP estimates.

Next I consider how two alternative data sources affect the results. In Column (5) I report relative military spending using a bilateral Törnqvist price index, as in Column (1), but where the relative price of Operations is measured using ICP-PPP data on relative transport services prices, rather than the price of GDP. This is an imperfect measure because, e.g., Operations is a far broader category including stores and maintenance and office services, and logistics. In addition, fuel costs in the defense sector are often subsidized, which would imply that the relative price of transport may overstate the prices the defense sector faces.[15] For the larger countries we see that Russia's relative military spending estimate falls slightly relative to Column (1), although this is still 28 percent above the GDP-PPP estimate. China's spending rises from 65 percent of US spending (Column 1) to 67 percent, and India's relative spending remains unchanged. For many other countries, relative spending falls modestly by this measure but typically still exceeds the value obtained using GDP-PPP exchange rates. In this case on average, the ratio military spending measured by military-PPP is still 36 percent higher than the values implied by GDP-PPP exchange rates.

Finally in Column (6), I report relative military spending where the relative cost of personnel is measured using the relative economy-wide average wage, rather than military wages. As the military wages are constructed from several sources, the use of average economy-wide wages provides a sense-check on the military wage data quality. In some countries, such as India, the defense sector wage rate is

[13]Multilateral indices are preferred insofar as they are transitive—which means that the PPP exchange rate between, say China and India, will equal the ratio of the China–US and India–US exchange rates (Fujikawa and Milana, 1996; Diewert, 1999; Van Veelen, 2002). Moreover, the ICP and Penn World Tables aggregate that PPP exchange rates are also constructed as multilateral indices of different price headings; therefore, in this sense the multilateral military-PPP index is more consistent with the Operations and Equipment price data. A disadvantage of the multilateral index, however, is that when there are some countries where data are less accurate, this may reduce the quality of all the data overall.

[14]The Multilateral Fisher is also known as the EKS method after Eltetö and Köves (1964) and Szulc (1964). For further discussion of the advantages and disadvantages of multilateral methods, see Caves *et al*. (1982b), Diewert (1999), Rao (2001, 2004) and Van Veelen (2002).

[15]The presence of fuel subsidies would result in an overestimate of unit transport costs, and therefore real military spending would be understated. I am grateful to an anonymous referee for this point.

very high relative to the average wage. In other countries, however, forms of conscription or wage subsidies substantially reduce wage costs to the defense sector.

It can be seen that the results again remain broadly similar to the base results in Column (1). China's estimated relative military spending rises from 65 percent to 70.9 percent of the USA and India's real relative spending rises to 44 percent of the USA from 37 percent in Column 1. The marginally higher values of real military spending relative to the base results in Column (1) reflect the fact that in both countries the premium for the defense sector is higher than the USA. Conversely, Russia's spending falls slightly, which suggests that a form of military wage subsidy exists.

A similar pattern exists in Korea, France, Brazil, and Greece. Nevertheless, while there are some changes in relative spending implied by the use of average economy-wide wages, the results show that the broad pattern remains.

6. Purchasing Power versus Military Power

I have derived measures of real military spending using a military-PPP exchange rate that incorporates domestic relative price differences across countries. The military-PPP exchange rate thus provides us with a means of comparing the real military budget of various countries that, in principle, are superior to using MERs or GDP-PPP exchange rates.

As noted above, however, insofar as all comparisons of military spending are input measures, they are only a starting point for comparing military capabilities. In considering military capabilities, one must also consider other non-budget factors such as public infrastructure, the efficiency of procurement, cancelations, and cost overruns (Hartley, 2017). Similarly, there may also be differences in organization, inter-operability, operational readiness, force multiplier technologies, and alliance strength. Likewise, we are only measuring the flow of annual expenditure, not the military capital stock of country. Large imbalances of expenditures between rivals have not always translated into military advantage, and the apparent effectiveness of militia forces such as the Taliban or the Vietcong countries where labor is very cheap is a source of discussion among defense analysts (Evans, 2003; Gates, 2009).

A second qualification when comparing defense budgets is that the military spending of a country often serves multiple purposes. For example, the defense sector may be used by governments as a means of creating employment, as a type of conspicuous consumption including parades and military bands, or as an instrument of international diplomacy through procurement deals. Therefore, the real "military services" delivered from an identical level of real spending in two countries may differ substantially depending on their strategic objectives and operational efficiency.

Therefore, estimates of real military spending only provide a guide to countries' relative defense capacities, and are conditional on defense objectives and extraneous non-budget factors. These differences between input and output concepts are, however, ubiquitous to all cross-country comparisons of military budgets, irrespective of the exchange rate concept.

7. Summary and Conclusion

International comparisons of defense spending are an important input into both national security strategies and national government budget decisions. There is dissatisfaction, however, over existing practices for converting military expenditure into units of a common currency. Very large differences in commonly used exchange rate concepts mean that the seemingly benign choice of exchange rate is often the single most significant source of uncertainty when comparing real defense spending across countries. While these exchange rate issues are routinely ignored, or considered very difficult to address, the emergence of middle-income military powers such as India and China, and the resurgence of Russia, mean they have become increasingly significant.

In principle, the correct way to compare military spending across countries is to use defense sector prices to construct a PPP exchange rate that is specific to the defense sector. Nevertheless, the data needed to impute these prices are often secret or simply not collected.

To address this, I develop a defense sector-specific PPP exchange rate based on RMCs using publicly available data on defense budget shares. For each country, this military exchange rate is constructed as a Törnqvist index of unit military costs relative to the USA. It can be readily applied using available data, satisfies important economic behavioral assumptions, and addresses the substitution bias inherent in cross-country expenditure comparisons.

I calculate real spending in $US and expressed relative to the USA, for 58 countries for 2017 and extended to 2019 in Appendix 4. I find that this results in very large differences in the estimated real relative balance of military spending across countries. For example, I find that that the purchasing power of spending in China is 73 percent larger than indicated by MERs and more than three times larger in India and Russia. This reduces the apparent dominance of the USA in terms of world military spending from over 40 percent of the global sample to just 26 percent. Rather than being larger than the next eight countries combined, when price differences are accounted for, US real military spending is shown to be smaller than the next two countries.

Moreover, I find that conventional GDP-PPP estimates also significantly understate military spending. On average spending as measured by defense sector military-PPP exchange rates is 1.44 times larger than GDP-PPP exchange rates. The difference is particularly large in countries with relatively high personnel intensive defense sectors, including Russia. More generally GDP-PPP exchange rates will be a poor approximation to defense sector exchange rates in low wage countries with labor-intensive defense sectors.

Overall the results show that the common practice of using MERs or economy-wide average price level PPP exchange rates results in highly misleading comparisons of real global defense spending levels, and understating real military spending relative to the USA. The relative-military-costs PPP exchange rate index provides an effective way to better compare real spending across countries and understanding the evolving real military balance.

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Supporting Information

Additional supporting information, Table A1–A4, may be found in the online version of this article at the publisher's web site:

Table A1: Military Expenditure Relative to the USA 2017
Table A2: Results for Alternative Superlative Index Numbers
Table A3: Transport Services - PPP as Price of Operations
Table A4: Real Military Spending (military-PPP) based on economy-wide Wage Rates