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International Comparisons of Real Military Purchasing Power: A Global Database

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Abstract

International comparisons of military spending are constrained by the unavailability of defense sector purchasing power parity exchange rates. I use new techniques, to construct a database of defence sector purchasing-power-parity exchange rates for 59 countries over nearly two decades. The results show that when defense-sector price differences are taken into account, the real defense budgets of countries such as Russia and China and India, are much larger than conventionally thought and that the USA's military budget occupies a much smaller share of world spending. The results have important implications for standard international comparisons of military spending that rely on market exchange rates or conventional purchasing power parity exchange rates.

Keywords: International Security; Military Spending, Defence Economics, Purchasing Power Parity, Price Indices, Index Numbers.

JEL: H56; O53; F5; C43.

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'My logisticians are a humorless lot ... they know if my campaign fails, they are the first ones I will slay.

Alexander the Great

1 Introduction

International comparisons of military spending are widely used to help understand the world security environment, plan defence budgets and as proxy measures of political and economic power. It is well known that the accuracy of these international comparisons is subject to limitations due to misreporting, secrecy, the treatment of para-military forces and dual use research uses, (ISSS 2006; O'Hanlon 2009; Smith 2009, Perlo-Freeman, 2011). While considerable effort is made to account for this lack of transparency, the most important source of error will often be from the seemingly innocuous process of converting spending into US dollars. These exchange rate issues are routinely ignored or consider too difficult to address. Nevertheless the rise of China, and emergence of India and resurgence of Russia, mean they have have become increasingly significant.

As an example, a well known US Department of Defense study of China's rise expressed alarm that its estimates of China's military budget in $US terms differed by over 200 percent depending on which exchange rate was used, (Crane et al 2005). By comparison, misreporting and classification errors for China are thought to be in the vicinity of 50%, (Perlo-Freeman 2014). Similarly current estimates of military spending in $US produced by the US Department of State vary by 78% for North Korea, 80% for Russia and more than 150% for India, depending on the exchange rate that is used (US Department of State, 2018). These enormous ranges are thus an important "known unknown" and remain a significant source of disquiet for defence agencies.[1]

Conceptually the correct measure to use is a military or defence sector exchange rate that measures the ratio of the implicit price of defense services across countries. This ratio would allow us to compare defense budgets in terms of their real purchasing power – defined the quantity military or defense services that spending can procure. While conceptually simple, the price or cost information required to construct a defense sector

[1]Other publishers such as the Stockholm International Peace Research Institute (SIPRI) and the International Institute for Security Studies (IISS) report spending using market exchange rates but also readily admit that they don't have a clear understanding as to which exchange rate concept is likely to be more accurate.

purchasing power parity (PPP) exchange rate either does not exist or is not widely available.

In this paper I show how an approximate military cost exchange can be computed using relatively easily available data across countries. This relative military cost (RMC) exchange rate is calculated for 58 countries relative to the USA over the period 2000-2017.

I find that in the majority of countries the real purchasing power of military spending is much higher than the values implied by the use of market exchange rates. Consequently the use of defense sector PPP exchange rates gives a very different picture of the global distribution of military spending. Specifically the USA share falls from over 40% of the global sample to just 25% while the shares of China, India and Russia increase significantly. Hence instead of the USA's defense budget being larger than the next eight countries, it is smaller than the next two countries.

The use of defense sector PPP exchange rates likewise changes the ranking of countries with large middle income countries gaining at the expose of developed NATO countries such as the UK, Germany and France. Overall the results also show that that market exchange rates are a poor method of comparing expenditure in many countries.

The results also answer an often asked question as to whether standard PPP exchange rates, designed to measure average consumer prices or the price of GDP, provide good estimates of military purchasing power. As examples I find that military purchasing power is 32% higher than the level implied by PPP exchange rates in China; 64% higher in Brazil; 58% higher in Indonesia; and 45% higher in The Ukraine. Hence standard PPP exchange rates understate relative military purchasing power in many countries, especially where there is a labour intensive defence sector and low wages. Nevertheless, large as these differences are, I find that PPP exchange rates provide much better approximations than market exchange rates.

The paper is organized as follows. The conceptual issues, comparing military spending across countries are set out in Section 2. Section 3 discusses the data and reports estimates of military exchange rates relative to the USA for 58 countries. These are then used to derive real military spending in $US for each country from 2000-2017.

2 Exchange Rates and Real Military Spending

International comparisons of defence spending are a key indicator of the global security landscape, (Beckley 2018). The standard method is to use market exchange rates to

convert spending one currency to US dollars, (U.S. Department of Defense, 2011; Crane et al, 2005; IISS, 2012; SIPRI 2012). Market exchange rates, however, tend to be a poor indicator of non-traded goods prices and labor costs. Consequently, because prices for non-traded goods are cheaper in lower income countries – the "Penn effect" – market exchange rates understate actual currency purchasing power in low income countries (Kravis et al 1978, Summers, Kravis and Heston 1980).

To address this problem purchasing power parity (PPP) exchange rates are constructed by sampling price levels in different countries. Typically this is done by comparing the price ratio of a basket of commodities. This price, or unit cost ratio, indicates the amount of currency needed to buy the same basket of goods in each country.[2]

Since defence sector spending also involves the procurement of non-traded goods and services, such as construction, housing and salaries, the "Penn effect" also implies that converting nominal military spending to $US dollars at market exchange rates will understate its purchasing power, (U.S. Department of Defense, 2011, IISS 2012). Publishers of military spending data, for example the IISS's The Military Balance and the SIPRI Yearbook and the Department of State WMEAT, therefore also report or discuss military spending across countries using standard PPP exchange rates.

Since these standard PPP exchange rates reflect average production prices, which may differ substantially from defence sector specific prices, they may be poor indicators of defense sector purchasing power (IISS 2012).[3] Nevertheless defence sector specific PPP exchange rates do not exist.

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 who are wiling to share sensitive data. Heston and Aten (1993) aimed to extend the analysis to 135 countries by regressing the observed military price levels of eight OECD countries on control variables such as per capita income. Since then there have been no attempts to expand the set of

[2]See for example Hill and Hill (2009), Diewert (2010) and Heston (2013) for general discussions and Deaton and Heston (2010) and Feenstra et al (2015).

[3]For example the IISS (2012) note that "no specific PPP rate exists for the military sector" and urge caution when interpreting their economic data since there is no definitive guide as to which elements of military spending should be calculated using the PPP rates available, (IISS 2012, pp.215-216). Likewise many studies have speculated that market exchange rates may provide a more realistic measure of military purchasing power than standard PPP exchange rates, due to the importance of imported components in defence spending such as electronics, arms and machinery, (Crane et al 2005, Gilboy and Heginbotham 2012, Frankel 2014).

survey countries.

Data on market exchange rates, PPP exchange rates, and labor costs should provide some upper and lower bounds on what the true defence sector PPP exchange rate might be. In what follows, I derive and apply a method that is pragmatic, insofar as it uses existing data that is widely available, but which is based on economic and index number theory. These defence sector PPP exchange rates can be computed utilizing data that is widely available for a large number of countries, in order to create a global database of military cost PPP exchange rates and real military spending.[4]

3 Measuring Military Purchasing Power

The key measurement problem in international comparisons of military spending is that there is no market price of defense services. If a price could be observed it would be straightforward to compare these across countries and create a defense sector PPP exchange rate. In the absence of defence sector output prices, the approach I take is to compare the prices of the components of military spending in order to construct an index of relative military input costs. As shown below, the ratio of military costs (RMC) is a defense sector PPP exchange rate.

Specifically let C_i be the defense budget in country i, in local currency units. This can be expressed as $C_i = M_i\ p_i$ where p_i is the unobserved price of military services and M_i is an unobserved real quantity index of defense sector output, which is an annual service flow. In order to compare the level of real annual defence sector service flows across countries, in principle, one simply needs to divide nominal spending by the price level in each country to obtain $M_i/M_k = (C_i/p_i)/(C_k/p_k)$. Hence the price ratio $e_{i,k} = p_i/p_k$ is the purchasing power parity exchange rate that converts i's spending into equivalent units of country k.[5] Thus letting k denote the USA, one can divide C_i by $e_{i,k}$ to obtain $p_k M_i$ which is i's real defense services M_i, evaluated in US dollars.

Since there is no market for national defense we cannot directly observe p_i. Nevertheless

[4]Some studies have used a weighted average of the PPP exchange rate and the market exchange rate, where the weights might reflect some characteristic such as the labour productivity of the defence sector, the personnel share of spending or estimates of imports (WMEAT, 2019, Crane et al 2005). The approach described here can be viewed as as using formal techniques to extend these intuitive approaches, particularly by including wage costs, and providing a rigorous framework that aids interpretation.

[5]Specifically if we set $M_i = M_k$ then it can be seen that $C_i/e_{i,k} = C_k$. Hence, for example, if C_i is China's spending China's spending in RMB, this tells us that C_i purchases the same amount of real services as $C_i/e_{i,k} = C_k$ in \$US.

under standard economic behavioral and production assumptions, p_i will equal the cost per unit of defense services which can be observed. While identifying the costs of various inputs that are used in the production of defense services is also a potentially very difficult task, data at a broad level of aggregation ins readily available. Specifically standard military budget reporting categorizes military spending into Personnel, Operations and Equipment spending (Brzoska, 1981, 1995). Hence it is possible to construct an input cost index from these categories based on their prices and expenditure shares in the overall defense budget. These unit cost indices then provide the basis estimating the implicit price ratio or defense sector PPP exchange rate $e_{i,k}$.[6]

A problem remains, however, that because countries have different defense needs and face different prices, the expenditure shares of each input will differ across countries. For example low wage countries may tend to have defense forces that rely more on personnel while high wage countries have defense forces that are more equipment and information intensive. These differing input choices mean that there is no unique way of comparing costs across countries, and the different approaches typically give very different results. For example, with respect to China and the USA, one could evaluate China's military inputs of personnel, operations and equipment at USA wages and prices. Alternatively one could evaluate the USA's defence sector input choices at Chinese prices. If the input choice differs across each country, then these two alternatives will give different answers.

This apparent inconsistency is a consequence of a more generic problem of substitution bias and is related to the Laspeyres and Paasche problem (Gerschenkron 1951, Feenstra et al 2015).[7] Fortunately index number theory offers a method for calculating relative inputs costs based on relative input prices which also controls for substitution bias. This requires using a superlative index number such as the Törnqvist price index.

3.1 The Törnqvist index on relative input costs

A Törnqvist price index provides a first order approximation to any arbitrary unit cost function that satisfies the usual economics behavioral and technological properties, (Diew-

[6]I draw on draw on standard economic behavioral and technology assumptions under which unit costs are a convex function of input prices.

[7]Interestingly while substitution bias is well known issue in economics it is attributed to a RAND study by Gerschenkron (1951) that aimed to measure Soviet output and so has its origins in international relations and the economics of military spending.

ert 1978, Allen and Diewert 1981, Hill 2006).[8] Hence, as shown by Robertson and Sin (2017) given the shares of defense spending for Personnel θ_i, Operations, γ_i, and Equipment $1-\theta_i-\gamma_i$ a first order approximation to an unknown relative military cost index, $e_{i,k}$, is given by

$$e_{i,k} = \; w_{i,k}^{\bar{\theta}} \; \rho_{i,k}^{\bar{\gamma}} \; r_{i,k}^{1-\bar{\theta}-\bar{\gamma}} \tag{1}$$

where $w_{i,k}$ $\rho_{i,k}$ and $r_{i,k}$ are, respectively, the prices of Personnel, Operations and Equipment in i relative to k and $\bar{\theta} = (\theta_i + \theta_k)/2$, $\bar{\gamma} = (\gamma_i + \gamma_k)/2$, and $1-\bar{\theta}-\bar{\gamma}$ are the average of the Personnel, Operations and Equipment shares of military spending in each country, i and k.

It can be seen that (1) it is a geometric average, rather than an arithmetic average. Hence as price increases or falls, the expenditure component rises or falls less than proportionally, which inherently accounts for substitution away from more expensive input choices in response to price changes. In this way the Törnqvist price index is a conceptual method for aggregating prices using economic principles to deal with substitution bias.

3.2 Defense Sector Input Prices

In order to implement (1) we require data on the relative price across countries for Personnel, Operations and Equipment, $w_{i,k}$, $\rho_{i,k}$ and $r_{i,k}$. To calculate the nominal relative prices of personnel, $w_{i,k}$, I use wage data adjusted for skill level differences, which are both available from the the Penn Word Tables.[9] This gives a skill adjusted wage ratio across countries, denoted $w_{i,k}$.

Second, since equipment is generally either traded or is tradable, relative equipment costs can be approximated by the market exchange rate (Crane *et al* 2005). Specifically for tradable goods the market exchange rate is the price that arbitrates purchasing power parity across countries, Hence $r_{i,k}$ is taken as the bilateral monetary exchange rate between country i and k, in units of i's currency per unit of k's currency. Finally, Operations consist of transport, storage, services and other inputs such as fuels. Since it

[8] A Fischer index is also be used and details and results are available on request.

[9] This assumes that defence sector wage profiles reflect wages in the rest of the economy, as a result of a labour market equilibrium. If conscripted defence forces are paid well below market wages the index would biased downwards for that country. The Mincerian skill index follows Klenow and Rodriguez-Clare (1997) by using the Mincerian relationship between the effective units of labor (human capital index) h, and years of schooling. Letting $\hat{p}_{n,i}$ denote the observed nominal labour price and h_i denote the Penn World Tables Index index of effective labour in country i, the nominal wage ratio per effective unit of labor is $p_{n,i}/p_{n,k} = (\hat{p}_{n,i}/\hat{p}_{n,k})(h_k/h_i) \equiv w_{i,k}$.

is a mix of traded and non-traded goods I use a standard average price PPP exchange rate as an approximation for the relative price of operations, $\rho_{i,k}$.

3.3 Data

The key data sources are the Penn Word Tables v9.1 (Feenstra et al 2015), the SIPRI Military Expenditure database, (SIPRI 2019), and the United Nations office for Disarmament Affairs (United Nations 2019). Additional data for China is taken from the 2019 China Defence White Paper, (State Council Information Office of the People's Republic of China, 2019).[10]

The relative price data, $\rho_{i,k}$, $w_{i,k}$ and $r_{i,k}$ are taken from the Penn World Tables. Specifically $\rho_{i,k}$ is the PPP exchange rate for i's currency per unit \$US, PPP_i^o. The value of $w_{i,j}$ is likewise taken from the Penn Word Table as the wage share multiplied by local currency current GDP. To allow for different skill levels across countries I use the Mincerian skill index which is also provided by the Penn World Tables.[11]

The expenditure share data, θ_i, γ_i, 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. Even with our sample of 59 countries there are also missing data resulting in interpolation for missing years, though the data also suggest that these shares do not vary substantially year to year. In a few cases data is supplemented from additional sources. Finally the actual military spending in local currency is taken from SIPRI (2019). Using these three principle sources we compute estimates of (1) for 59 countries over 17 years from 2000 to 2017 giving 1062 observations. The 59 countries in the sample cover 86.6% of world military spending on a market exchange rate basis.[12]

[10] Appendix 2 contains a more detailed discussion of the data sources.

[11] Their method follows Klenow and Rodriguez-Clare (1997) by using the Mincerian relationship between the effective units of labor (human capital index) h, and years of schooling. The nominal local currency levels of military spending are taken from SIPRI. The SIPRI values contain adjustments for paramilitary and other types of spending that harmonizes the definition of military spending across countries.

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

Naturally the military share and military spending data is imperfect due, for example, to misreporting or a lack of transparency. Nevertheless this is a generic problem in international comparisons of defense spending. Since imperfect data is preferable to simply ignoring the issue of price differences the RMC approach provides way forward for deriving better quality comparisons of real defense spending across countries. A related issue is that there may be differences in efficiency across countries. Hence the real services delivered from a dollars worth of spending in two countries may differ substantially if one country has a much more efficient defense sector. This is an important issue which means that caution is required when interpreting the data as measures of real defense capabilities, as opposed to real defense purchases. Again, however, this is a generic issue and the same caveat applies irrespective of exchange rate measurement issues.

4 Results

Table 1 summarizes the results for all 59 countries for the latest year 2017. Specifically it reports the resulting implied values of real military spending in PPP terms using the both the traditional market exchange rate and using RMC defense sector PPP exchange rate $M_i/e_{i,k}$ from (1). The countries are ranked according to the size of their military spending. For ease of comparison Table 1 also reports the each country's military spending relative to the USA. The full set of results for 2017, including the exchange rate calculations and their components can be seen in Appendix Table A1.

It can be seen, first, that RMC exchange rates generally imply much higher real military purchasing power than market exchange rates. For example, China's 2017 military budget converted to $US using market exchange rates is $US228 billion. But in defense sector PPP terms wages it is equivalent to is $US481 billion. This means that in order to generate the same level of defence services in the USA as China currently produces, albeit with a different input mix, it would cost $US481 billion – nearly double the market exchange rate value.

Hence as shown in Table 1, based on market exchange rates, China's military spending in 2017 ($228 billion) was 37.65% of the USA, but with the RMC exchange rate the real purchasing power is 79.46% of the USA ($US481b).[13] Likewise, in defense sector

[13]The details of the derivation of this result can be seen in Table A1. An explicit example may help. The market exchange rate is RMB 6.8 per dollar, relative wage costs are just RMB 1.2 per dollar. This indicates that in order to purchase a dollars worth of the same quality labour in China, an individual would only need 1.2 RMB – less than the market rate of 6.8 RMB per dollar. Averaging these relative

PPP terms, India's defense budget ($US281 billion) rises from approximately 10% of the USA to 46% of the USA and the third largest military in the world, leapfrogging Russia. Russia falls from 3rd to 4th place but its military spending but nevertheless the size of its budget increases from $66 billion or 11% of the USA in market exchange rate terms to $190 billion in RMC terms and 31 percent of the USA.

Second it can be seen that there is a significant change in the ranking of countries. As we have seen India leapfrogs Russia in terms of military purchasing power. Similarly Brazil leapfrogs a number of countries in terms of its real military spending rising from 10th largest in market exchange rate terms to 5th place in defense sector PPP terms, passing France, U.K, Germany, Korea and Japan. Relative to the USA, Brazil's defense budget is 4.8% of the USA on market exchange rate basis but 12.37% of the USA in terms of military PPP exchange rates. Other countries that move up the rankings dramatically are Ukraine, which moves up 14 places from 32 ranked to 18th, and Indonesia which moves up six places from 19th the 13th. For Indonesia the military PPP exchange rate yields military purchasing power that is 6.02% of the USA (versus 1.35% of the USA under market exchange rates) and for the Ukraine military purchasing power is 3.69% of the USA (compared to just 0.6% of the USA using market exchange rates). Similar increases in relative size are seen in Philippines, Peru and Kazakhstan. In contrast the countries that move down the rankings are the wealthier OECD countries such as France, Japan, Germany, and Great Britain, Belgium, Denmark and Finland. On average across countries, defence sector purchasing power is 2.56 times higher than the levels implied when market exchange rates are used.

input costs according to their expenditure shares then gives a military cost PPP exchange rate of RMB 4.2 per dollar – to purchase a $US worth of military services in China, it would only take approximately 4.2 RMB. Hence dividing China's 2017 military budget of RMB 1541 billion by 4.2, rather than the market exchange rate of 6.8, gives $US481 billion or 79% of the USA's 2017 defence budget of $605 billion.

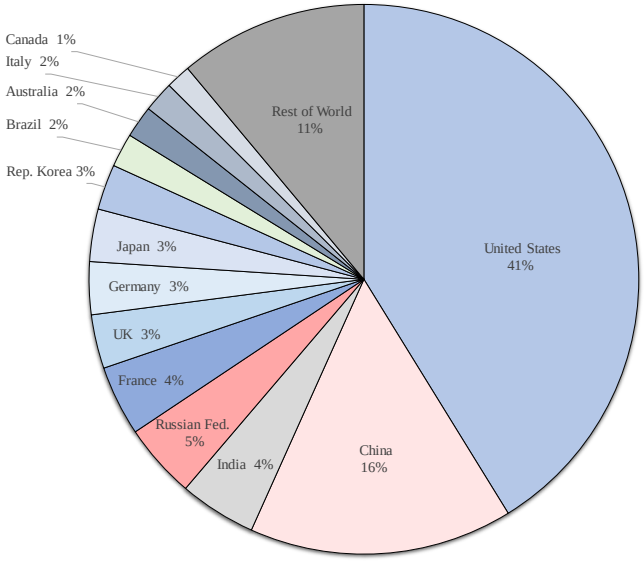
Table 1: Countries Ranked by Military Expenditure, 2017

Rank	Country	Spending in $USm RMC-PPP	Percent of USA	Rank	Country	Spending in $USm MER	Percent of USA
1	United States	605803	100.00	1	United States	605803	100.00
2	China	481372	79.46	2	China	228067	37.65
3	India	281760	46.51	3	Russian Fed.	66502	10.98
4	Russian Fed.	190416	31.43	4	India	64640	10.67
5	Brazil	74945	12.37	5	France	60680	10.02
6	France	65773	10.86	6	UK	46602	7.69
7	Rep. of Korea	62507	10.32	7	Germany	45579	7.52
8	Japan	60897	10.05	8	Japan	45358	7.49
9	UK	56835	9.38	9	Rep. of Korea	39323	6.49
10	Germany	56542	9.33	10	Brazil	29179	4.82
11	Turkey	41634	6.87	11	Australia	27685	4.57
12	Colombia	40996	6.77	12	Italy	26563	4.38
13	Indonesia	38219	6.31	13	Canada	21372	3.53
14	Italy	35265	5.82	14	Turkey	17611	2.91
15	Australia	27406	4.52	15	Spain	16113	2.66
16	Canada	24729	4.08	16	Colombia	10006	1.65
17	Poland	22500	3.71	17	Poland	9977	1.65
18	Ukraine	22341	3.69	18	Netherlands	9622	1.59
19	Spain	21647	3.57	19	Indonesia	8168	1.35
20	Philippines	21498	3.55	20	Norway	6463	1.07
21	Mexico	20647	3.41	21	Mexico	5778	0.95
22	Chile	14618	2.41	22	Sweden	5536	0.91
23	Malaysia	12806	2.11	23	Argentina	5456	0.90
24	Argentina	12334	2.04	24	Chile	5363	0.89
25	Netherlands	11157	1.84	25	Greece	5116	0.84
26	Peru	11111	1.83	26	Switzerland	4628	0.76
27	Romania	9525	1.57	27	Belgium	4504	0.74
28	Greece	8892	1.47	28	Denmark	3780	0.62
29	Norway	6222	1.03	29	Philippines	3755	0.62
30	Portugal	5872	0.97	30	Portugal	3662	0.60

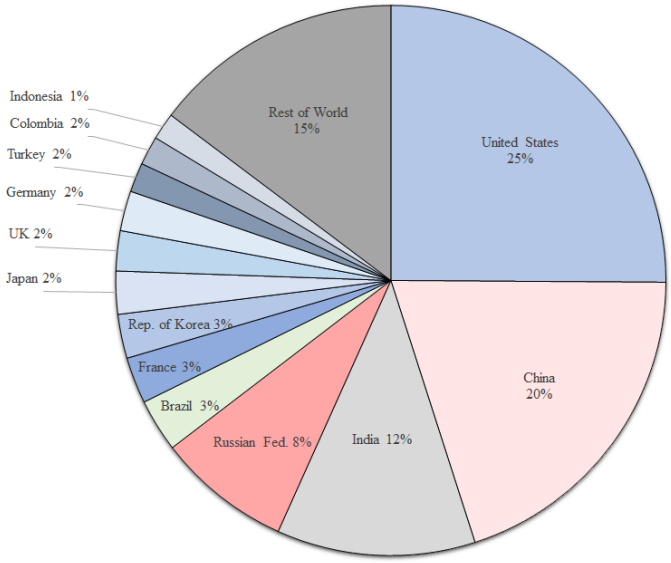
Table 1 (ctd): Countries Ranked by Military Expenditure, 2017

Rank	Country	Spending in $USm RMC-PPP	Percent of USA	Rank	Country	Spending in $USm MER	Percent of USA
31	Sweden	5597	0.92	31	Romania	3643	0.60
32	Kazakhstan	5297	0.87	32	Ukraine	3635	0.60
33	Czech Republic	4653	0.77	33	Malaysia	3511	0.58
34	Belgium	4566	0.75	34	Finland	3445	0.57
35	Switzerland	4169	0.69	35	Austria	3152	0.52
36	Finland	3694	0.61	36	Peru	2670	0.44
37	Denmark	3676	0.61	37	New Zealand	2323	0.38
38	Austria	3592	0.59	38	Czech Republic	2092	0.35
39	Hungary	3148	0.52	39	Hungary	1468	0.24
40	Bulgaria	3129	0.52	40	Kazakhstan	1388	0.23
41	Serbia	3070	0.51	41	Uruguay	1165	0.19
42	New Zealand	2772	0.46	42	Slovakia	1054	0.17
43	Uruguay	2547	0.42	43	Ireland	1030	0.17
44	Slovakia	2160	0.36	44	Bulgaria	828	0.14
45	Senegal	1885	0.31	45	Lithuania	816	0.13
46	Croatia	1758	0.29	46	Serbia	812	0.13
47	Armenia	1616	0.27	47	Croatia	787	0.13
48	Lithuania	1575	0.26	48	Estonia	540	0.09
49	Burkina Faso	1459	0.24	49	Latvia	512	0.08
50	Ireland	1211	0.20	50	Slovenia	476	0.08
51	Guatemala	1086	0.18	51	Armenia	444	0.07
52	Latvia	942	0.16	52	Cyprus	359	0.06
53	Estonia	890	0.15	53	Senegal	308	0.05
54	Slovenia	831	0.14	54	Guatemala	275	0.05
55	Trin & Tob.	520	0.09	55	Trin & Tob.	203	0.03
56	Cyprus	496	0.08	56	Burkina Faso	192	0.03
57	Jamaica	469	0.08	57	Jamaica	144	0.02
58	Republic of Moldova	244	0.04	58	Malta	65	0.01
59	Malta	102	0.02	59	Republic of Moldova	31	0.01

(i) Distrubution of Military Spending - Market Exchange Rates



(ii) Real Military Spending - Defense Sector PPP Exchange Rates (RMC)



World Distribution of Military Spending

The fact that military purchasing power is much larger than is suggested by exchange rate comparisons in many countries means that allowing for differences in defense sector prices also significantly changes the global distribution of real military spending. This can be seen in Figure 1 which reports the same data for the largest countries as a fraction of total spending in the sample, and compares this with the traditional picture based on market exchange rates.

As noted above the sample of 59 countries accounts for approximately 86.6% of world spending. Panel (i) of Figure 1 shows that using market exchange rates the USA accounts for 41% percent of this global sample. Likewise, on a market exchange rate basis, the USA defense budget is larger than the next eight countries combined. As shown in panel (ii), however, on a defense sector PPP basis – using the RMC exchange rate – the USA's defense budget only accounts for 25% of world spending while China alone accounts for 20%. Hence in defense sector PPP terms the USA's defense budget is not much bigger than China. Moreover it is smaller than either combination of China and Russia (28%) or China and India (32%) and these three countries account for 40% of spending in the global sample.

The fall in the USA share reflects that fact that world military purchasing power is much higher than suggested by market exchange rates. Moreover, while military purchasing power is larger in most countries the bulk of the increase in global spending is attributable to just three large countries China, India and Russia. Together these three countries account for 63% of the 1.64 fold increase in estimated global real military spending when defense sector PPP exchnage rates are used relative to market exchange rates.

The key result, therefore, is that market exchange rates dramatically understate real purchasing power of military spending in many countries. This effect is greatest in countries where prices differs substantially from USA prices. This reflects the the fact that some country's defence sector's are very labour intensive and also that non-traded goods and services prices in developing countries tend to be lower than traded goods prices – the "Penn effect".

4.1 Military Costs and Standard PPP Exchange Rates

The results so far indicate that market exchange rates perform very poorly as an indicator of defense sector purchasing power, understating military purchasing power in most countries and resulting to a distorted view of the size of developed countries defense spending relative to other countries – particularly the size of the USA relative to China,

India and Russia. An important question that remains then is, to what extent do RMC exchange rates differ from standard GDP-PPP exchange rates that are readily available? If they are very similar then we would have established that standard PPP exchange rates provide a good approximation to defense sector purchasing power exchange rates. If they differ it will point to the importance of using defense sector specific PPP exchange rates, such as the RMC exchange rate, for international comparisons. Further questions then arise as to why they differ and whether there is any systematic pattern that reveals any insights about the nature of defense sectors that might be useful.

The first point to emphasize is that, even though the results reflect the "Penn effect", it does not follow that standard PPP exchange rates will be a good indicator of defense sector purchasing power. Typically PPP exchange rates are designed to measure economy-wide average price differences such as the price of GDP or the cost-of-living.[14] An exchange rate designed to compare these broad price averages will not necessarily reflect international differences in defence sector prices. In particular, some writers have speculated that the capital intensity of military spending and use of imported equipment, may mean that market exchange rates provide a better predictor of military purchasing power that these PPP exchange rates (Crane et al 2005, Gilboy and Heginbotham 2012, Frankel 2014). Thus questions remain over how much the RMC defence sector PPP exchange rates derived here differ from standard GDP-PPP exchange rates, in which countries they differ most, and why?

The difference between RMC defence sector PPP exchange rates, $e_{i,k}$ and GDP-PPP exchange rates, $\rho_{i,k}$ can be seen on the vertical axis of Figure 2 which reports the ratio of of military purchasing power calculated using RMC exchange rates relative to GDP PPP exchange rates, $(C_i/e_{i,k})/(C_i/\rho_{i,k}) = \rho_{i,k}/e_{i,k}$. For convenience the values for 2017 are highlighted with country labels. The remaining points for other years give a sense of the sample variance across time. The horizontal axis simply show GDP per capita PPP for each country-time observation.

As can be seen that the RMC exchange rate estimates of military purchasing power are significantly larger than the values implied by the Penn world tables PPP exchange rates (GDP-PPP) with most values lying above unity. For example in China the RMC estimate of China's military budget is 32% higher (1.32 times higher) than the Penn World Tables GDP-PPP estimate. In Russia, military purchasing power is approximately

[14]The World Bank's International Comparison Project collects a wide range of goods and services to compare GDP. These are placed under broad categories heading so that in principle indices of GDP and consumption or other types of spending can be compared across countries. Thus the Penn World Tables reports consumption, government and investment price indices (World Bank 2013).

23% higher than implied by the GDP-PPP exchange rate. Moreover in some countries this difference is very large. For example in Brazil, Indonesia, Ukraine and Mexico the military cost PPP estimates of purchasing power are 40-60% higher than the GDP-PPP based estimates. Moreover in Columbia the military cost estimate is 1.81 times (81%) larger than the GDP-PPP estimate and in the Philippines it is more than 100% larger.

The results therefore show that the GDP-PPP exchange rates also tend to understate the real purchasing power of military spending, and that this difference can also be very large. Using a simple average across countries, military purchasing power is 34% larger than what is implied by the Penn World Table GDP-PPP exchange rates. These differences are also indicated by the in Table A1 also which reports $(C_i/e_{i,k})/(C_i/\rho_{i,k}) = \rho_{i,k}/e_{i,k}$. Hence, on average, RMC exchange rates, which reflect military purchasing power, appear to be much closer to standard PPP exchange rates than they are to market exchange rates, but still substantially smaller resulting in substantially larger defence sector purchasing power estimates.

Figure 2 also shows that there is also substantial variation between GDP-PPP exchange rates and the RMC defence sector PPP exchange rates. In some countries the RMC and GDP-PPP exchange rates are very similar, while in others the RMC ratio is less than half the PPP-GDP exchange rate so that real purchasing power is more than double the value implied by using standard PPP exchange rate. As can be seen in Figure 2 the variance is high for low and middle income countries but is much lower for high income countries. Moreover for middle and low income countries the ratio varies between unity and approximately 4, but rarely falls below unity. Since the "Penn effect" implies $r_{i,k} > \rho_{i,k}$, it is straightforward to see from equation (1) that the condition $\rho_{i,k}/e_{i,k} > 1$, depends on the relative wage component of the index, $w_{i,k}^{\bar{\theta}}$, being small. Specifically countries where real military purchasing power is much higher than the level implied by GDP-PPP exchange rates, are those which have low real wages but where the wage bill occupies a large fraction of the defence budget.

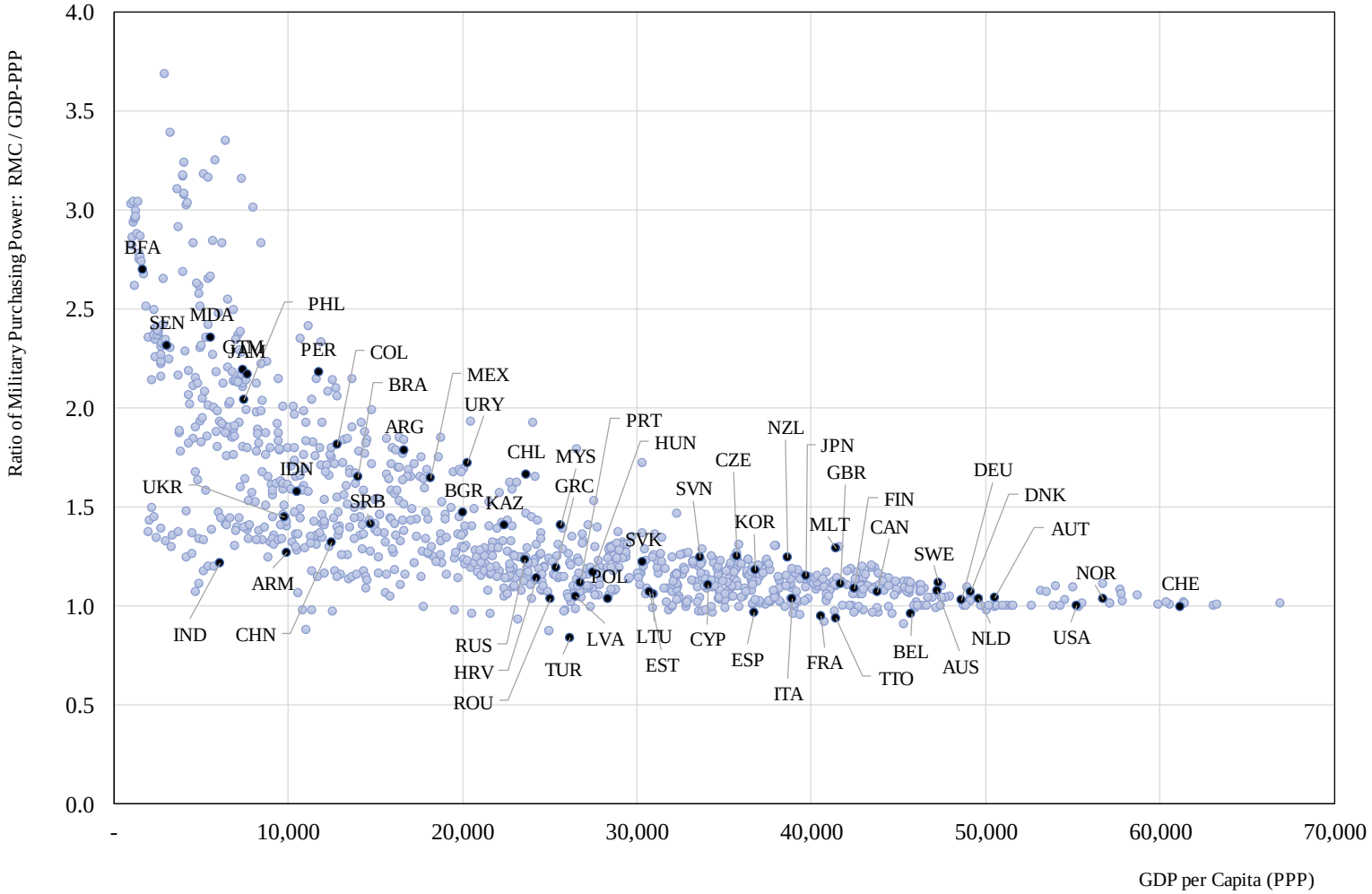


Figure 2: Real Wages, and $\rho_{i,k}/e_{i,k}$ across country-time observations

Because countries with low wages tend to have more labor intensive defense sectors there is a strong correlation between per capita GDP and military purchasing power relative average purchasing power of goods and services, $\rho_{i,k}/e_{i,k}$. Thus all of the countries that have high values of $\rho_{i,k}/e_{i,k}$ – meaning RMC estimates of military purchasing power that exceed the PPP estimates – also have low wages costs and hence low GDP per capita. Likewise the richer countries are clustered around $\rho_{i,k}/e_{i,k} = 1$, indicating that the RMC estimates and GDP-PPP estimates tend to give very similar results, which reflects that fact that their wage cost structures are similar to the USA.

Thus for China the RMC estimate is 32% larger than GDP-PPP estimates and so China has a value of 1.32 on the horizontal axis in Figure 2. China therefore lies close to to the mean value of $\rho_{i,k}/e_{i,k}$ of 1.34 and also is fairly normal for countries in similar wage levels. Nevertheless, this 32% difference is clearly very significant given China's size and importance. Conversely it can be seen that a number of middle income countries, such as Mexico, Colombia, Argentina, Brazil, Uruguay, have relatively low levels of per capita GDP and also RMC purchasing power estimates that are around 50% larger than PPP estimates, $\rho_{i,k}/e_{i,k} = 1.5$. These countries all have low real wages and relatively large personnel shares in their defence budgets and so GDP-PPP estimates considerably understate defence sector purchasing power.

It is instructive to compare India with China, and some of these middle income countries. India's GDP is lower than China's but the ratio of RMC and GDP-PPP exchange rates is smaller than China at 1.21. This result reflects the fact that both countries spend approximately 40% of their military budget on Equipment. Hence's India's Equipment share is large relative to the aevrage level at this lower level of per capita income. In contrast, for example, Colombia's equipment share is just 7% of its defence budget. A country like the Ukraine is in the middle with a procurement share of 19%. Thus while India, Colombia and Ukraine all have fairly low per capita incomes, there is a substantial difference in the RMC and GDP-PPP exchange rates in these countries. These variations in equipment and personnel shares largely explain the variance in the ratio of RMC and PPP based estimates on the vertical axis, $\rho_{i,k}/e_{i,k}$.

Hence the military PPP exchange rates naturally reflect differences different choices each country makes about how to produce military services. In India's case the military is relatively capital intensive despite being a country with very low-cost labor, whereas in the case of Colombia, the equipment share of the budget is relatively small, suggesting its defence strategy is much more dependant on personnel. Ukraine sits in between these two examples. These alternative uses of factor inputs in providing defence services naturally may reflect a range of factors from strategic choices about the level and nature of threats

to more economic based considerations over government budget management. The RMC exchange rate accounts for these different choices in response to different factor prices in a natural way insofar as it implicitly allows for substitution between different expenditures to allow for different approaches to delivering defence services depending on the prices faced in each country.

Figure 2 thus shows that the extent to which PPP exchange rates understate defence sector purchasing power is quite extreme in some poor countries. For example in Burkina-Faso the personnel share is 75% of its military budget and in Senegal it is 65%. These countries' armed forces are, therefore, lightly armed, and possibly more equivalent to militias. As evidenced by militia forces such as the Taliban or the Vietcong, this type of defence force may provide effective defence services in countries where labor is very cheap but where stealth technology is offset with suicide bombers (Evans 2003, Gates 2008). The relatively high value of these military services when defence sector specific purchasing power (RMC) is used reflects the fact that types of militia forces would be relatively expensive to produce at USA wages. Whether or not they provide effective defence is a matter of debate. Nevertheless for very poor countries, machetes and suicide bombers are low cost and may be the only effective defence option.

While these relatively low wage militia type armed forces – particularly in African and the Caribbean – provide extreme examples, the effect of wage differences and personnel shares on relative military costs is also quite notable in larger countries with substantive military forces. In particular in the middle-income South America countries, as well as countries like Ukraine and Indonesia and, to some extent, also Russia and China, we find that both market exchange rates and GDP-PPP exchange rates considerably understate the actual military purchasing power, and this is related to the relatively low wages, intensity of personnel use and relative lack of equipment spending.

5 Summary and Conclusion

International comparisons of defence spending are an important input into both national security strategies and national government budget decisions. Nevertheless there is dissatisfaction over existing practices for converting military expenditure into units of a common currency. Very large differences in PPP and market exchange rates mean that this, seemingly benign, comparison process is typically most significant source of uncertainty when assessing the real size of foreign defense spending.

In principle the correct way to compare military spending across countries is to use defense sector prices to construct a purchasing power parity exchange rate that is specific to the defence sector. Since output prices are not observable, I develop an exchange rate based on relative military input costs using defence budget share data. For each country the defense sector PPP exchange rate is constructed as a Törnqvist index of unit military costs relative to the USA. The RMC exchange rate index can be readily applied using available data, satisfies important economic behavioural assumptions and addresses the substitution bias inherent in cross-country expenditure comparisons.

I therefore calculate real military purchasing power in $US and expressed relative to the USA, for 58 countries from 2000-2017. I find that the purchasing power of spending in China, India and Russia 2 to 4 times larger than indicated by market exchange rates. On average market defense spending purchasing power is 2.56 time larger than indicated by market exchange rates. Thus it is also shown that allowing for defense sector price differences casts a very different light on the world distribution of military spending, reducing the apparent dominance of the USA from over 40% of the global sample to just 25%.

Similarly conventional GDP-PPP estimates also understate military spending. On average spending according to defense sector PPP exchange rates spending is 1.34 time larger than GDP-PPP exchange rates. The difference is particularly large in countries with relatively high personnel intensive defense sectors – such as militia-type defence forces – tend to have much higher purchasing power than conventional exchange rate estimates suggest.

Hence conventional international comparisons of military spending can be be highly misleading, and tend to understate purchasing power relative to the USA. The RMC defense sector PPP exchange rate provides an effective way to better compare real spending across countries and hence better understand the evolving global military balance.

Appendix 1: Detailed Results for 2017

Detailed results for all countries, for 2017, are given in Table A1 below. [15] Table A1 reports the cost shares for Personnel, where $\bar{\theta}$, Operations, $\bar{\gamma}$ and Equipment, $1-\bar{\theta}-\bar{\gamma}$, in Columns (1)-(3). Columns (4)-(6) report the wages per effective worker in each country relative to the USA, $w_{i,k}$, the Penn World Tables value of the GDP PPP exchange rate, $\rho_{i,k}$, and the current market exchange rate, $r_{i,k}$. The resulting RMC military exchange rate is reported in Column 7.

The levels of military expenditure in each country relative to the USA, M_i/M_k, in Column (10). This is derived using and SIPRI data on the military expenditure in in each country in local currency, and dividing by $e_{i,k}$ in column (7). Specifically dividing the nominal military spending ratio in Column (10) by the RMC exchange rate in Column (7) gives the real military spending ratio, M_i/M_k. For comparison Columns (8) and (9) report military spending relative to the USA using conventional market exchange rates and PPP exchange rates. Hence comparing the values in columns (8) and (9) with (10) shows the impact of using the RMC exchange rate relative to conventional measures. To facilitate comparison columns (11) and (12) report the ratio on spending in RMC terms relative to market exchange rates and PPP exchange rate.

[15] The full set of results for ten years and workings are available on request.

Table A1: Military Expenditure Relative to the USA 2017

Country Code	Country	(1) Personnel Share	(2) Operations Share	(3) Procurement Share	(4) Market exchange rate	(5) Wage ratio	(6) GDP-PPP exchange rate	(7) Törnqvist RMC exchange rate $e_{i,k}$	(8) Mil.Exp % USA. MER $(C_i/C_k)/r_{i,k}$	(9) Mil.Exp % USA GDP-PPP $(C_i/C_k)/\rho_{i,k}$	(10) Mil.Exp % USA RMC $(C_i/C_k)/e_{i,k}$	(11) Ratio (10)/(8)	(12) Ratio (10)/(9)
USA	United States	0.36	0.42	0.22	1.0	1.0	1.0	1.0	100.0	100.0	100.0	1.00	1.00
CHN	China	0.31	0.28	0.41	6.8	1.2	4.2	3.2	37.6	60.2	79.5	2.11	1.32
IND	India	0.31	0.28	0.41	65.1	3.8	18.1	14.9	10.7	38.3	46.5	4.36	1.21
RUS	Russian fed.	0.41	0.16	0.42	58.3	11.5	25.1	20.4	11.0	25.5	31.4	2.86	1.23
BRA	Brazil	0.58	0.28	0.15	3.2	0.6	2.1	1.2	4.8	7.5	12.4	2.57	1.65
FRA	France	0.60	0.28	0.12	0.9	0.8	0.8	0.8	10.0	11.5	10.9	1.08	0.95
KOR	Rep. of Korea	0.35	0.28	0.37	1,130	457	839	711	6.5	8.7	10.3	1.59	1.18
JPN	Japan	0.41	0.35	0.24	112	62	96	84	7.5	8.7	10.1	1.34	1.15
GBR	UK	0.44	0.37	0.19	0.8	0.5	0.7	0.6	7.7	8.4	9.4	1.22	1.11
DEU	Germany	0.35	0.48	0.17	0.9	0.6	0.7	0.7	7.5	9.1	9.3	1.24	1.03
TUR	Turkey	0.48	0.37	0.14	3.6	1.0	1.3	1.5	2.9	8.2	6.9	2.36	0.84
COL	Colombia	0.50	0.17	0.33	2,951	377	1,307	720	1.7	3.7	6.8	4.10	1.81
IDN	Indonesia	0.77	0.20	0.03	13,381	1,102	4,506	2,860	1.3	4.0	6.3	4.68	1.58
ITA	Italy	0.59	0.25	0.16	0.9	0.6	0.7	0.7	4.4	5.6	5.8	1.33	1.03
AUS	Australia	0.69	0.08	0.23	1.3	1.2	1.4	1.3	4.6	4.2	4.5	0.99	1.08
CAN	Canada	0.49	0.35	0.16	1.3	1.0	1.2	1.1	3.5	3.8	4.1	1.16	1.07
POL	Poland	0.52	0.33	0.15	3.8	1.0	1.7	1.7	1.6	3.6	3.7	2.26	1.04
UKR	Ukraine	0.49	0.22	0.28	26.6	1.6	6.3	4.3	0.6	2.6	3.7	6.15	1.45
ESP	Spain	0.59	0.24	0.17	0.9	0.6	0.6	0.7	2.7	3.7	3.6	1.34	0.96
PHL	Philippines	0.59	0.19	0.23	50.4	2.7	18.0	8.8	0.6	1.7	3.5	5.72	2.04
MEX	Mexico	0.54	0.39	0.06	18.9	2.6	8.7	5.3	1.0	2.1	3.4	3.57	1.64
CHL	Chile	0.68	0.21	0.11	649	155	395	238	0.9	1.5	2.4	2.73	1.66
MYS	Malaysia	0.85	0.15	0.00	4.3	0.6	1.7	1.2	0.6	1.5	2.1	3.65	1.40
ARG	Argentina	0.51	0.44	0.04	16.6	4.7	13.1	7.3	0.9	1.1	2.0	2.26	1.79
NLD	Netherlands	0.84	0.12	0.04	0.9	0.7	0.8	0.8	1.6	1.8	1.8	1.16	1.03
PER	Peru	0.53	0.29	0.17	3.3	0.3	1.7	0.8	0.4	0.8	1.8	4.16	2.18
ROU	Romania	0.71	0.19	0.10	4.1	0.8	1.6	1.6	0.6	1.5	1.6	2.61	1.04
GRC	Greece	0.55	0.10	0.36	0.9	0.3	0.6	0.5	0.8	1.2	1.5	1.74	1.19
NOR	Norway	0.52	0.21	0.26	8.3	8.5	8.9	8.6	1.1	1.0	1.0	0.96	1.03
PRT	Portugal	0.39	0.33	0.28	0.9	0.4	0.6	0.6	0.6	0.9	1.0	1.60	1.11

Table A1 (ctd): Military Expenditure Relative to the USA 2017

Country Code	Country	(1) Personnel Share	(2) Operations Share	(3) Procurement Share	(4) Market exchange rate	(5) Wage ratio	(6) GDP-PPP exchange rate	(7) Törnqvist RMC exchange rate $e_{i,k}$	(8) Mil.Exp % USA. MER $(C_i/C_k)/r_{i,k}$	(9) Mil.Exp % USA GDP-PPP $(C_i/C_k)/\rho_{i,k}$	(10) Mil.Exp % USA RMC $(C_i/C_k)/e_{i,k}$	(11) Ratio (10)/(8)	(12) Ratio (10)/(9)
SWE	Sweden	0.63	0.11	0.26	8.5	7.4	9.4	8.5	0.91	0.83	0.92	1.01	1.11
KAZ	Kazakhstan	0.31	0.33	0.36	326.0	36.3	120.0	85.4	0.23	0.62	0.87	3.82	1.41
CZE	Czech Republic	0.44	0.51	0.05	23.4	6.7	13.1	10.5	0.35	0.61	0.77	2.22	1.25
BEL	Belgium	0.60	0.28	0.12	0.9	0.9	0.8	0.9	0.74	0.79	0.75	1.01	0.96
CHE	Switzerland	0.78	0.16	0.06	1.0	1.2	1.1	1.1	0.76	0.69	0.69	0.90	1.00
FIN	Finland	0.36	0.35	0.29	0.9	0.7	0.9	0.8	0.57	0.56	0.61	1.07	1.09
DNK	Denmark	0.42	0.35	0.23	6.6	6.4	7.3	6.8	0.62	0.57	0.61	0.97	1.07
AUT	Austria	0.51	0.42	0.06	0.9	0.7	0.8	0.8	0.52	0.57	0.59	1.14	1.04
HUN	Hungary	0.61	0.25	0.14	274.4	74.3	149.3	128.0	0.24	0.45	0.52	2.14	1.17
BGR	Bulgaria	0.42	0.41	0.17	1.7	0.2	0.7	0.5	0.14	0.35	0.52	3.78	1.47
SRB	Serbia	0.68	0.23	0.08	107.8	11.1	40.2	28.5	0.13	0.36	0.51	3.78	1.41
NZL	New Zealand	0.45	0.41	0.14	1.4	0.9	1.5	1.2	0.38	0.37	0.46	1.19	1.25
URY	Uruguay	0.53	0.37	0.10	28.7	8.7	22.5	13.1	0.19	0.24	0.42	2.19	1.72
SVK	Slovakia	0.84	0.14	0.03	0.9	0.3	0.5	0.4	0.17	0.29	0.36	2.05	1.22
SEN	Senegal	0.58	0.21	0.21	582.1	30.2	220.4	95.2	0.05	0.13	0.31	6.12	2.32
HRV	Croatia	0.65	0.23	0.12	6.6	2.0	3.4	3.0	0.13	0.25	0.29	2.23	1.14
ARM	Armenia	0.60	0.26	0.14	482.7	49.2	168.0	132.5	0.07	0.21	0.27	3.64	1.27
LTU	Lithuania	0.33	0.54	0.13	0.9	0.2	0.5	0.5	0.13	0.25	0.26	1.93	1.06
BFA	Burkina Faso	0.36	0.22	0.42	582.1	25.8	206.3	76.6	0.03	0.09	0.24	7.60	2.69
IRL	Ireland	0.77	0.11	0.13	0.9	0.7	0.7	0.8	0.17	0.21	0.20	1.18	0.97
GTM	Guatemala	0.78	0.12	0.11	7.3	0.8	4.1	1.9	0.05	0.08	0.18	3.95	2.19
LVA	Latvia	0.71	0.28	0.01	0.9	0.3	0.5	0.5	0.08	0.15	0.16	1.84	1.05
EST	Estonia	0.34	0.30	0.36	0.9	0.3	0.6	0.5	0.09	0.14	0.15	1.65	1.07
SVN	Slovenia	0.27	0.26	0.46	0.9	0.4	0.6	0.5	0.08	0.11	0.14	1.75	1.24
TTO	Trin. & Tobago	0.73	0.21	0.06	6.8	1.2	2.5	2.6	0.03	0.09	0.09	2.57	0.93
CYP	Cyprus	0.39	0.16	0.46	0.9	0.6	0.7	0.6	0.06	0.07	0.08	1.38	1.10
JAM	Jamaica	0.78	0.11	0.11	128.0	19.1	85.2	39.3	0.02	0.04	0.08	3.26	2.17
MDA	Rep. of Moldova	0.76	0.14	0.10	18.5	0.9	5.5	2.3	0.01	0.02	0.04	7.96	2.35
MLT	Malta	0.72	0.28	0.00	0.9	0.4	0.7	0.6	0.01	0.01	0.02	1.58	1.29

Apppendix 2: Data and Sources Variables

The key data sources are the Penn Word Tables v9.1 https://www.rug.nl/ggdc/ productivity/pwt/, SIPRI Military Expenditure database, and the United Nations office for Disarmament Affairs UNODA (UN 2019). Additional data for China is taken from the 2019 China Defence White Paper, State Council Information Office of the People's Republic of China, (2019).

Military expenditure component share data for all countries are from United Nations Office for Disarmament Affairs (UNODA) online data (United Nations 2019)) with the exception of a few years for China and India. China's military share data from 2000-2003, 2005, 2007, 2009 - 2017 are taken from various issues China Defence White papers. The latest White paper which contain military expenditure shares from 2010 to 2017 is available in UNODA website also. China's 2006 and 2008 share data are taken from UNODA. China's 2004 shares were interpolated. For India, data from 2000 - 2011 were taken from Center for Strategic and International Studies (CSIS) (2012). India's 2012 - 2014 and 2017 data were taken from UNODA.

US military share data from 2001 - 2008, 2010 - 2011 and 2013 - 2015 are from UNODA reports. There are other sources for military shares especially for US such as white house historical tables available from https://www.whitehouse.gov/omb/historical-tables/. In these historical tables, Table 3.2 - Outlays by Function and sub function provides details on military share. However there are changes in classification of expenditure under these two sources. For example; accruals and government contribution to retirements for civilians employed by Department of Defence (DoD) is included under military personnel cost in UNODA report where as it is included under Operations and Maintenance cost in white house tables. Additionally, all atomic energy defence activities including weapons, materials production, naval reactor development and verification technology is included under procurement and construction in UNODA classification whereas it is a separate item in the Whitehouse report. For years where UNODA data is not available the White House shares have been used to interpolate the UNODA reported shares

The wage and exchange rate data are taken from the Penn World Tables v9.1, (Feenstra et al 2015) which is available online.[16] Specifically the PPP-GDP exchange rate rho_{ik} is given by the PPP exchange rate for i's currency per unit \$US, PPP_i^o, where PPP_i^o is the PPP price level, pl_cgdpo multiplied by the nominal market exchange rate, $PPP_{china}^o = pl\_gdpo_{china} \times xr_{china}$. This PPP exchange rate converts i's nominal current

[16]See https://www.rug.nl/ggdc/productivity/pwt/

GDP local currency units into PPP dollars measured in dollars of a base year, which is 2011 in the PWT. For consistency with the relative wage exchange rate and market exchange rates it is necessary that the base current US prices are the current year. Thus I calculate the relative PPP exchange rate between country i and the USA as $(pl\_cgdpo_i \times xr_i)/pl\_cgdpo_{usa}$.[17] Thus I divide the local currency to \$US constant dollar PPP exchange rate by the \$US PPP price index, pl_cgdpo_{usa} to compare price levels in local currency units with price levels in the USA, in the same year.

[17]Note that $xr_{usa} = 1$ for all years.

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