The Loaded Gun: Energy Surplus and the Balance of Power

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Abstract

What's the best measure of military potential? National power usually is measured by comparing nations' relative wealth or military capability, GDP and CINC scores for instance, but both are crude proxies. I argue that the best measure of force projection potential is access to energy surplus because it captures a hard limit on interstate competition. Global surplus energy production reveals the distribution of power up for grabs at any given time. My main finding is that energy surplus not only co-varies with the intensity of interstate conflict enough to support the common intuition that major wars consume energy, but also that it maintains a power-law distributed hierarchy in doing so. This implies that the balance of power has a tangible structure that defines both the status quo and the means by which it is challenged.

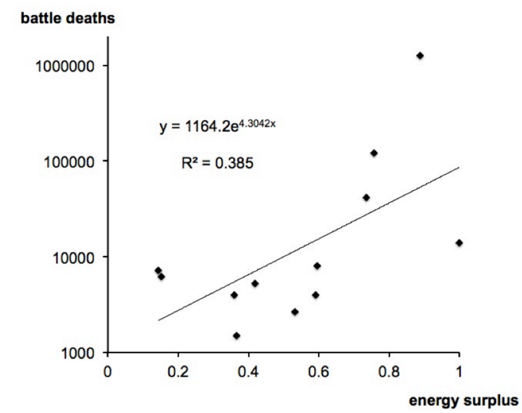
Power conversion

Whether you're planning a war or trying to prevent one, or both, you probably think you need to know something about the military capabilities of the potential rivals. But what if the thing you really need to know is how much convertible force projection capability exists in the world overall? What if the probability of any particular outcome can't be determined by looking at pairs of states, and instead rests on subtler factors that constitute the underlying global balance of power at any given time?

In that case, you would care less about the details of Chinese coal production, Russian natural gas exports, or the U.S. fracking boom than you would about where each of these fits within the global economic order. Big countries can be relied upon to constantly improve their capacities to fuel warships, cargo planes, bombers, and their nuclear infrastructure, but what governs these refinements is beyond even the most powerful country's complete control. Maximizing one's control depends on how much there is to be controlled. It is entirely a matter of converting matter into energy for the purpose of perpetually and advantageously reorganizing, or disorganizing, matter. The social science of grand strategy axiomatically must be a physical science about this conversion. And since the world economy is now a single physical system, it probably makes less and less sense to study it as if apart from the same laws of conservation of energy that apply everywhere else. More parochial metrics such as currency wealth or steel production can't possibly be as reliable as just measuring the conversion potential itself. Political power is literally power, and my initial empirical tests using energy as the main unit of analysis bear this out.

I'll elaborate on these claims using language and concepts borrowed from complexity theory, combined with a synopsis of the conventional literature on interstate competition, to first demonstrate that the world political and economic systems really do behave like a single system that obeys physical laws. I'll then thoroughly elaborate on the causal logic that I think explains the observed connection between world energy balances and war. Lastly, I'll summarize the empirical method and results that appear to confirm this logic. From this I draw no specific policy recommendations other than to conclude that strategists and policy makers would be wise to reorient their thinking about war and the balance of power toward this more physical and macroscopic view.

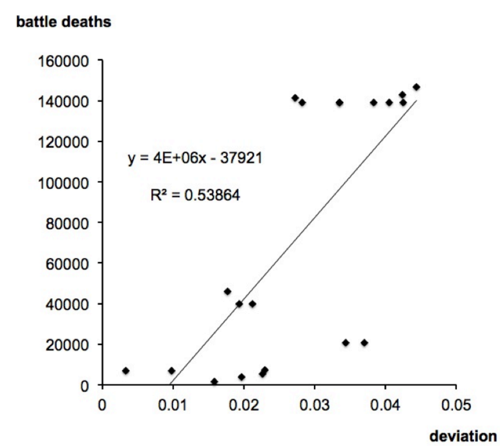
Figure 1. World surplus energy production (normalized) vs. battle deaths from interstate wars initiated, 1980-2003 (lin-log)



Sources: U.S. Energy Information Administration, 2014; Correlates of War data (Sarkees 2010). Does not include years with no war initiated. See also Richardson 1960; Cederman 2003; Cioffi-Revilla 2004; Bohorquez 2009.

A complex, physical system

Figure 2. Deviation from power-law distribution of energy production vs. battle deaths from interstate wars initiated, 1980-2003 (lin-lin)

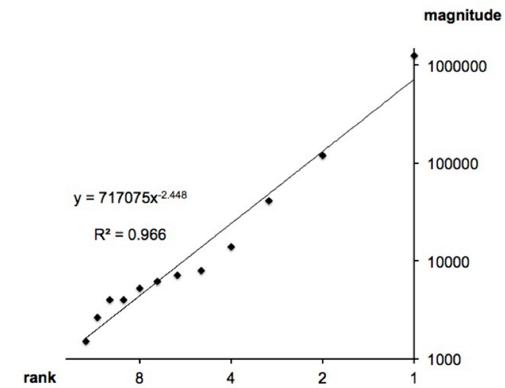


Source: Compiled from sources cited in fig 1.

There is a tentative correlation between world surplus energy production and the intensity of modern interstate wars. Of greater significance is the correlation between war intensity and deviation from a typical distribution of national energy production. The hierarchy of nations is characterized by a consistently proportional concentration of material power at the top, and disturbances in this hierarchy seem to be corrected by conflict between its members.

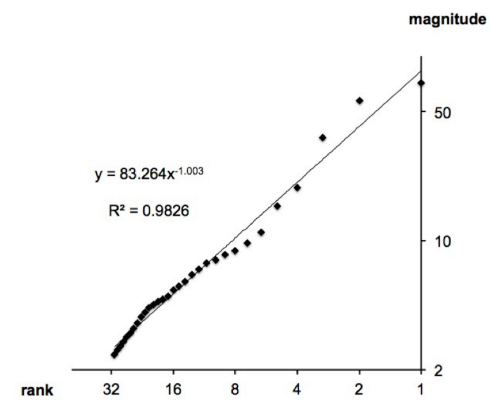
It's already well established that wars are reliably intense in proportion to their rareness. Major wars do not vanish into the right tail of a normal distribution, but instead are power-law distributed, making them scale invariant, or proportionally likely at any scale. There is no average war size or upper limit other than maximum lethality (Richardson 1960; Cederman 2003; Cioffi-Revilla 2004; Bohorquez 2009; Pinker 2011).

Figure 3. Battle deaths from interstate wars initiated in a given year, 1980-2003 (log-log)



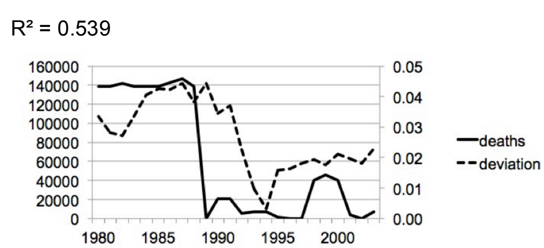
Source: Correlates of War data (Sarkees 2010). See also Richardson 1960; Cederman 2003; Cioffi-Revilla 2004; Bohorquez 2009.

Figure 4. Top 31 countries' annual energy production (quadrillion Btu), average distribution 1980-2011 (log-log)



Source: U.S. Energy Information Administration, 2014.

Figure 5. Battle deaths vs. deviation from power-law distribution of energy production



Source: Compiled from data in fig 3 and 4. Battle deaths computed from war totals divided by duration in years.

When observed in nature, according to complexity theorists, this signature regularity usually indicates a constant buildup or charge that requires periodic release (Bak 1996). We know that energy production, the fuel of peacetime expansion, also fuels force projection capability. It makes sense that this raw ingredient of conflict should vary with the thing it enables. As it turns out, energy as a source of offensive power also is power-law distributed when comparing countries in any given year over the last three decades. The distribution is tight, with an average (best-fit) 0.98 linear correlation on a log-log rank-magnitude plot. Deviations loosely correlate to the intensity of wars, as if to suggest the wrong distribution of energy production is a systemic charge that builds up and is released through armed hostilities.

In order to properly frame the analysis, it must be noted that complexity theorists are not the first to try to analyze war processes scientifically, and scientific analysis does not automatically imply mindless indifference to the role of decision-making in these processes. Conventional international relations theory recognizes, for example, the importance of the security dilemma, i.e. the observation that arming to prevent attack by a potentially hostile power may trigger an arms race, spiraling up the probability of what was supposed to be prevented (Herz 1950, 157; Waltz 1979, 186). National leaders face this dilemma within the structural constraints of their relative positions within the international system, a configuration known as the balance of power (Waltz 1979, 117). And scientific analysis of the balance of power requires information about national capabilities (131). Although international relations scholars have long debated what is the most stable balance of power, they generally see inequality in the distribution of capabilities as normal. The question remains, what is the most stable inequality (132)?

The traditional debate over polarity, i.e. the ideal number of great powers at the top (129), had to be amplified to answer this question. One prevailing amplification was the theory of hegemonic stability (Keohane 1980), which states that world order requires a single dominant power to stabilize the system (Kindleberger 1973; Keohane 2005). Power transition theory goes a step further to look for the conditions under which stability fails, such as the rise of a challenger (Organski 1968).

Branches of power transition research had to depart from system-level theory because of the need to examine dyadic pairs of states to compute changes in relative power (Geller 1992; Schampel 1993).

This was aided by J. David Singer and the Correlates of War Project, the purpose of which was to use the scientific study of war to teach leaders and the public how to avoid war. Singer was modest about the prospect of achieving this (Singer 2000, 6).

Dyadic analysis complicates system-level analysis, though, and at first seems best suited to inform only behavioral theories on war triggers, rather than global probabilities of war. There are many pairs to examine, and identifying efficient causes that apply to all of them is difficult. It introduces complex questions like the relevance of pairs (Xiang 2010) that end up pointing back to system-level, structural constraints.

Nevertheless, prominent work on power transition managed to merge dyadic analysis back into system-level theory by returning to capability concentration and systemic power distribution (Geller 1992). A significant result of this was the finding that a closing power gap between two great powers only tends to trigger war when it involves a system-level decrease in power concentration (280). That is, deviation from the naturally unequal distribution of power is fundamentally destabilizing.

Although this seems to imply, in the end, that unipolar hegemony is the key to stability, it is not so simple. There is evidence that from 1980-2003 (the period under study in my analysis), a too-heavy concentration of material power in the hands of the top country was associated with more intense systemic conflict, even though in the same period deviation from an overall power-law distribution (which still requires a proportionally heavier concentration on the upper end) is generally associated with conflict. In other words, what matters is not simply that there be a concentration of power, but rather that it remain distributed a certain way. Systemic deviation seems to require systemic correction through armed conflict, whether the deviation or the correction is brought about by a challenger or the status-quo power itself.

Energy surplus as war trigger

World surplus energy production is, as mentioned earlier, loosely correlated with the intensity of interstate wars initiated in any given year from 1980-2003. This does not necessarily negate the conventional intuition that, since wars consume energy, energy surplus should be associated with peace instead of war. But it potentially does call it into question. In the period under study, overall increases in countries' combined surpluses are indeed associated with an apparent overall decline in conflict. But most of these surpluses are consumed through trade. When examining only the leftover global surplus (total production minus total consumption), and only in years in which interstate wars broke out, the resulting intensity of those wars does appear to correlate loosely (R^2=0.39) with the global surplus that existed in the years of war initiation. It is important to note that no inference of efficient cause can be drawn from such a tentative correlation. It is also important to note that efficient cause is not the principal target of complex systems analysis. Because complex systems analysis involves optimal combinations of multiple factors that evolve into the most probable of many possible outcomes, also known as ultimate cause, something like energy surplus in a given year probably can only be seen as firing a gun that already was on hair trigger to begin with. Surpluses may just be the signifiers of national production already having reached levels that are out of proportion with a balanced inequality of power.

Disturbance in balanced inequality, i.e. deviation from the finely tuned hierarchy of power between nation-states, is I suggest the ultimate cause that generates war even though it does not always precede war in time. It may even occur in tandem with it, or closely follow it, pointing to equally powerful anticipatory effects.

For example, a challenger may see a potentially closing power gap with the lead power and initiate war to accelerate the disturbance and overtake the leader (Geller 2000, 268; in Vasquez 2000), in which case the largest deviation from a balanced inequality would occur after the outbreak of, and even after the conclusion of, major war. This kind of inconsistency in the direction of causation is somewhat unfamiliar but not entirely new to social science (Kessler 2010, 27-28; Kurki 2008). It is more familiar to evolutionary biologists and others for whom complex optimization processes matter far more than random event triggers

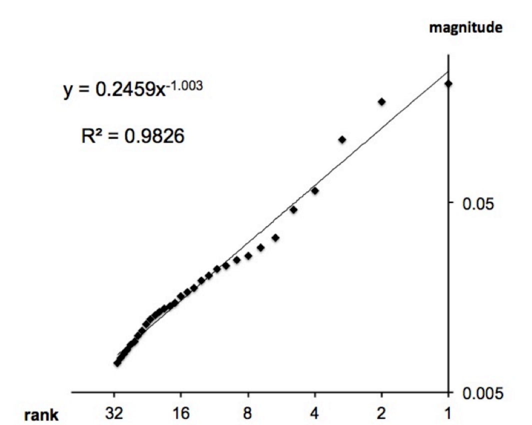
Also, the struggle may take place through proxies or through attempts to influence less powerful resource suppliers, which also might produce a lag in which the ultimate cause, a disproportionate or critical change in relative power, post-dates the war effect. Sometimes the resulting wars may just be trickle-down conflicts, not directly related to the energy requirements or military standing of the great powers. Again, in complex systems causation does not have to be direct: Wars for independence or seemingly isolated border disputes can be the indirect and opportunistic ripple effects of distant changes in the balance of power. The wars of the 1980s and 1990s included all of these types, from major interstate wars and energy wars, such as the Iran-Iraq war and the Gulf war, to smaller independence wars, for example Bosnia and Kosovo, not to mention the many border wars which vary greatly in scale (Sarkees 2010). In spite of the diversity and seeming disconnectedness of these wars, when combined they reliably produce a characteristic empirical signature that can't be ignored (see fig 3).

Behind that empirical signature potentially lies another one, what has so far been described as balanced inequality. What does a balanced inequality look like? When based on a slight rounding of the normalized average distribution of the top 31 energy producers from 1980-2011, i.e. those with the best power-law fit, it turns out to resemble this surprisingly simple function, where *x* is country rank and *f(x)* is a country's normalized (0.0 - 1.0) portion of total world energy production for a given year:

$$f(x) = 0.25\, x^{-1}$$

Of note is the -1 exponent, which is the slope of the power-law trend on a log-log plot and the constant by which countries' energy production tends to scale in any given year. Generally, when the absolute value of the exponent on a rank-magnitude plot is greater than 1, it means each increase in rank gets a proportionally greater increase in magnitude. When the absolute value of the exponent is less than 1, each increase in rank gets a proportionally lesser increase in magnitude. In real-world terms, systems with a greater-than-one exponent are said to be unsustainable because of their more rapid scalability, whereas those with a less-than 1 exponent are said to be sustainable but less dynamic (West 2004). It is interesting that the distribution of energy production by country so closely lies in or approximates the middle. It seems to support the notion of a balanced inequality, although at present this is little more than a

Figure 6. Top 31 countries' annual energy production (normalized), average distribution 1980-2011 (log-log)



Source: Data used in fig 4.

symbolic basis for the claim. Note especially, however, that the absolute value of the exponent in fig 1, the rank-magnitude distribution of interstate wars from 1980-2003, is greater than 2 (highly scalable, highly unstable, and potentially unsustainable when reaching a certain extreme level of destruction).

How are changes in the balanced inequality of national energy production and energy surplus associated with critical events in the form of militarized international crises, whether directly or indirectly?

Once again it is necessary to borrow concepts from natural science that remain unfamiliar to social scientists. The previously mentioned process of charge or buildup and release is described as *self-organized criticality*, or the inherent tendency of a physical system to produce accumulation that reaches a critical state without design or external intervention. Common examples include earthquakes, which happen randomly but in proportion to the amount of geologic pressure built up over time, and forest fires, which also happen randomly but in proportion to the amount of fuel accumulated since the last conflagration. A heuristically clearer example that has been replicated in laboratories is the random but proportionally distributed scale-frequency tradeoff (rank-magnitude consistency) of avalanches produced by a steady stream of grains of sand falling onto a sand pile (Bak 1986; Cederman 2003; Cioffi-Revilla 2004).

It is easy to see how this would be analogous to war and the buildup of systemic charge in the form of collective offensive capability such as available surplus energy, with the specific timing or cause of a given war trigger largely irrelevant or at least unknowable. But if some change in the distribution of energy production or other source of offensive capability is the hypothetical buildup toward a critical state that results in organized violence, there remain two central questions: What makes the distribution of material capabilities so important and so consistent, and why are changes in the distribution associated with criticality in the form of militarized international crisis?

Answering those questions requires at least superficial knowledge of two additional concepts borrowed from systems theory and the natural sciences: Cumulative advantage and metabolic efficiency.

Cumulative advantage is the tendency of some advantage to lead to scalable future advantages such that competitors in a system are proportionally separated by increasing distances over time. The process can be replicated in statistical models by repeatedly multiplying any set of random values by other random values so that over time the distances between them vary exponentially. Numerous regularities emerge from this simple test of randomness, to include similarities in the resulting distributions regardless of scale or number of results selected. Slightly more complicated random-walk experiments produce a similar behavior, except that the overall exponential distribution, which is not scale invariant, only approaches a power-law distribution that is increasingly invariant at the upper tail. Further technical analysis is beyond the scope of this argument and not necessary anyway: What matters is that the general process is not mysterious but is a function of normal probability. Colloquially known as the rich-get-richer effect, cumulative advantage also relates to but is not technically identical to more specific effects such as the Yule process used in biology and Pareto distributions used in economics (Newman 2006; Pinker 2011).

It turns out to be the case that several measures of national capability follow such a distribution, not just energy production or consumption. The ubiquity of this feature does not prove that cumulative advantage is the explanatory mechanism, but the fact that it appears in an openly competitive system points in that direction. What's more important is that the behavior supplies a constant, or in this case a hierarchical norm, enabling longitudinal analysis of changes in that norm and their possible effects.

Although both energy production and energy consumption trends, as well as those of other measures of national capability, obey this norm to a high degree, surplus energy production does so to a high but notably lesser degree. This is likely because of the dramatic degree to which the larger producers can shift export-import balances over time.

Table 1: Average power-law fitness on best-fit country distribution (0.0-1.0 log-log R^2 rank vs. magnitude correlation) of various measures of national material capabilities or national power.

Period	**Energy prod.**	**Energy consum.**	**Energy surplus**	**GDP**	**Iron & steel prod.**	**Military expend.**
1980-1989	0.96	0.98	0.94	0.98	0.99	0.98
1990-1999	0.98	0.98	0.95	0.98	0.97	0.98
2000+	0.98	0.99	0.94	0.99	0.98	0.98

Table 2: Average power-law fitness on all-country distribution (0.0-1.0 log-log R^2 rank vs. magnitude correlation) of various measures of national material capabilities or national power.

Period	**Energy prod.**	**Energy consum.**	**Energy surplus**	**GDP**	**Iron & steel prod.**	**Military expend.**
1980-1989	0.88	0.92	0.86	0.93	0.91	0.93
1990-1999	0.89	0.92	0.87	0.94	0.90	0.93
2000+	0.89	0.92	0.86	0.94	0.93	0.93

This slightly more lopsided distribution in surplus energy markets may be a key source of disruption or uncertainty in the otherwise balanced inequality between countries in total national energy production as a proxy for national power. If the global energy market can be viewed, not just metaphorically, as a thermodynamic or metabolic system with inefficiencies requiring perpetual resolution, it may be useful to break out of strictly economic and political paradigms and look at how other sciences have begun to tackle similar problems within their own domains.

Metabolic efficiency. Biologists have begun to integrate statistical and mathematical principles used in physics with the process of theory construction and testing in their own field. One of the outcomes of this has been a better understanding of metabolic efficiency and allometric scaling, i.e. the power-law covariances between animal mass and various measures of animal metabolism, including life span, and how these enrich existing theories of resource competition and evolution (West 2004).

Studies of allometric scaling have pointed to what are called dynamic energy budget processes that efficiently allocate the energies required for homeostasis versus the surplus energies used in dynamic activities such as growth and reproduction (Sousa 2008). Metabolic efficiency has its own cumulative advantage properties, as larger animals benefit from economies of scale that are governed by a power-law constant, explaining why elephants live longer and sleep less than mice while both have roughly the same number of heartbeats in a lifetime. Taken down to the level of the individual organism, the concept of metabolic efficiency becomes even more critical: The cardio-vascular system has evolved across species to optimize oxygen supply to meet oxygen demand in the bloodstream through a process known as impedance matching, or matching of the sizes of arteries, veins, and capillaries to the rate of blood flow so that the volume is the same at all levels and variances caused by resistance are minimized. Failure to minimize those variances leads to cardiac arrest or other complications, obviously reducing the organism's evolutionary competitiveness (West 2004).

The purpose of considering the concept of metabolic efficiency as a candidate process to be applied in examining the relationship between national capability and war is not to draw absurd analogies between animals and nation-states. Rather the purpose is to draw on the operative component concepts such as network efficiencies and energy budgeting to consider, at an abstract level at first, potentially law-like explanations for how the unequal but normally stable political economy of energy actually works, why it exhibits regularities that resemble those found in the natural sciences, and how it fails and leads to crisis.

Relatively minute but critical disturbances in the balance of power are associated with heightened levels of lethality, but not necessarily involving the major energy producers, as already discussed. Changes in the balance of power also must be associated with trickle-down disruptions in the broader political economy. As with a defective cardio-vascular system, these create a surge of resistance sufficient to disrupt normal economic flows, perhaps catastrophically, especially in the smaller and more vulnerable economies that lack the cumulative advantages of scale and longevity. Although global energy markets are highly adaptive (Gholz 2010), political and diplomatic arrangements may not be so immune. Trade relations are a known conduit for exposure to disruption. Relative power has been identified as a missing variable in the impact of trade on conflict (Xiang 2007), and when accounted for this variable reveals that, contrary to conventional beliefs about interdependence and peace, close economic ties can actually make militarized conflict between countries more likely, depending on their relative power (Xiang 2007, 2010). When combined with evidence that the closing of power gaps amid decreased power concentration leads to conflict (Geller 1992), the possible connection between disrupted flows and violent political conflict comes into sharper focus.

In short, great-power war might be like the world system having a heart attack. At the risk of overextending the analogy, it should come as no surprise then that empirical analysis testing the sensitivity of war to disruptions in capability distribution will resemble the output from an electrocardiogram.

Measures of power and war sensitivity compared

I have already shown that energy production and other measures of national power follow a seemingly self-regulating power-law distribution of proportional concentration at the top, with a high degree of consistency. I have also hinted that variances in the degree of consistency (i.e. lapses into inconsistency) over time are associated with the intensity of conflict. What is to be inferred is that war probability is sensitive to seemingly minor variances in these otherwise typical distributions of power.

How is that relationship measured? I draw on seven measures of power (Singer 1972 et al; Singer 1987; Bolt and Van Zanden 2013; U.S. Energy Information Administration 2014) using three ways of measuring concentration for each, for ultimately 21 measures of concentration of power. Three of the seven measures of power involve energy, and the rest include GDP and three metrics from the Correlates of War dataset on National Military Capabilities (version 4). These include iron and steel production and military expenditure, as well as the Composite Index of National Capabilities (CINC). The three ways of measuring concentration are meant to cover concentration at three levels: Top country, top set of countries, and all countries. Concentration of power in the hands of the top country is a simple measure of share of total. For groups of countries I look for two ideal distributions: Countries that fall within the "best fit" power law distribution (i.e. the set of top countries with the best R^2 for the natural log of each country's rank compared to the natural log for its magnitude) constitute the distribution that is characterized as “max fit” (R^2) or “minimum deviation” ($1 - R^2$). The other ideal distribution is simply the power-law fit for all countries. With these 21 measures of concentration in hand for each year, I then compare concentration of power to battle deaths in interstate wars for each year from 1980-2003 (Sarkees 2010), the best data available and which includes the initial state-on-state phases of 21st century U.S. intervention in Iraq and Afghanistan. Battle deaths for every set are measured using two different methods: On the one hand, I look at battle deaths distributed annually for the duration of each militarized interstate conflict, since consistent data was not readily available for each year separately; and, on the other hand, I look at the total number of battle deaths resulting from every militarized interstate conflict begun in a given year.

All of this results in 42 measures of correlation between power concentration and interstate war intensity. A positive correlation implies that power concentration is associated with more intense wars, while a negative correlation (in parentheses in the tables) implies the opposite. This does not account for frequency of wars or number of wars, but since wars are power-law distributed such that low frequency is offset by high intensity, and since wars are only nominally discrete phenomena, it makes sense to look at battle deaths per year, and also resulting from a war-initiation year, as the measures of war intensity. Generally, higher concentration in the top power is associated with more intense wars. The exception, counter-intuitively, is military expenditure by the top power, which seems to be associated with less war, perhaps supporting the defense policy side of the theory of hegemonic stability, or deterrence theory generally. In any case, energy production, energy surplus, and GDP all are associated with less war when concentrated among powerful countries proportionally (in a balanced hierarchy), but not the single top country when its share is apparently disproportionate.

Table 3: Concentration of power vs. battle deaths (annual), 1980-2003

Measure of power	**Covariance of [top country's percent of total power] with [annual battle deaths from interstate wars]**	**Covariance of [max fitness to 1.0 log-log distribution of power] with [annual battle deaths from interstate wars]**	**Covariance of [overall fitness to 1.0 log-log distribution of power] with [annual battle deaths from interstate wars]**
Energy production	0.67	(0.54)	(0.39)
GDP	0.10	(0.41)	(0.77)
CINC score	0.64	0.18	(0.01)
Military expenditure	(0.47)	(0.45)	(0.58)
Iron & steel production	0.62	0.27	0.21
Energy consumption	(0.04)	(0.10)	0.00
Energy surplus	0.12	0.00	(0.05)

Table 4: Concentration of power vs. battle deaths (year initiated), 1980-2003

Measure of power	**Covariance of [top country's percent of total power] with [initiated battle deaths from interstate wars]**	**Covariance of [max fitness to 1.0 log-log distribution of power] with [initiated battle deaths from interstate wars]**	**Covariance of [overall fitness to 1.0 log-log distribution of power] with [initiated battle deaths from interstate wars]**
Energy production	0.22	(0.05)	0.00
GDP	0.00	(0.04)	(0.20)
CINC score	0.09	0.25	0.12
Military expenditure	(0.15)	(0.03)	(0.05)
Iron and steel production	0.03	0.01	0.03
Energy consumption	0.33	(0.03)	0.56
Energy surplus	0.68	(0.38)	(0.19)

Table 5: Concentration of power vs. battle deaths (annual), 1980-2003 (longitudinal)

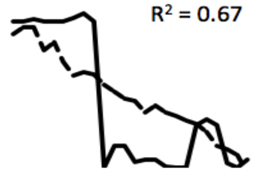
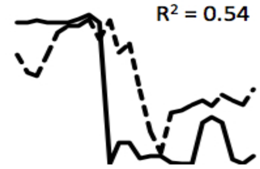
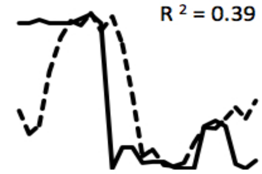
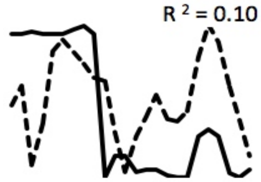
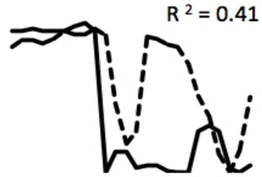
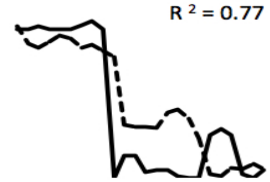
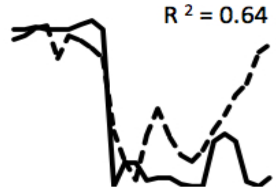
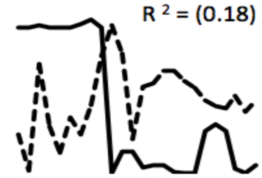
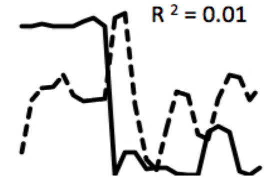
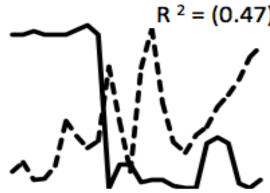
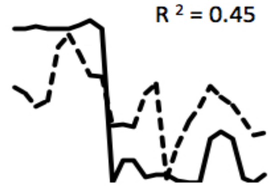
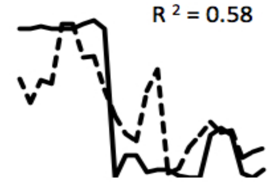
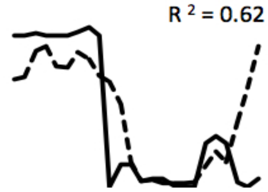
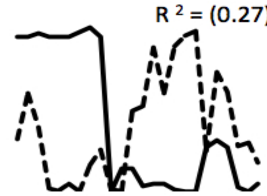
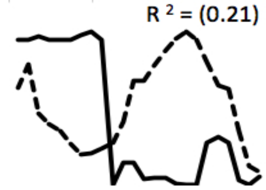
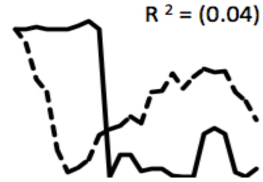
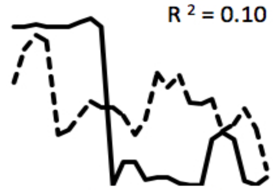
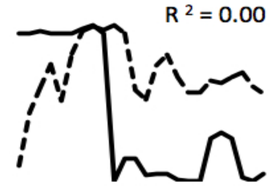
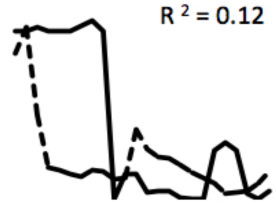
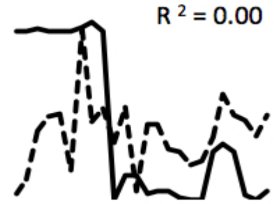
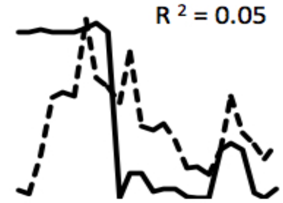
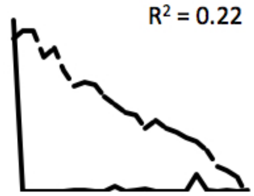
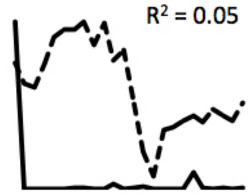
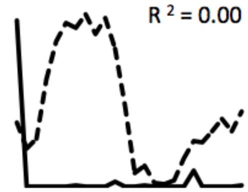
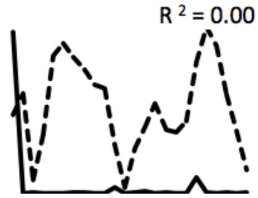
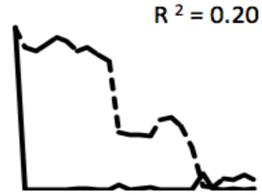
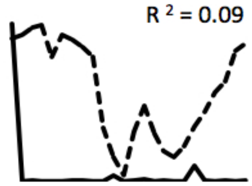
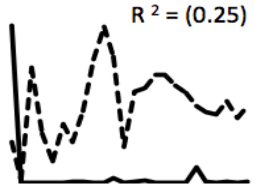
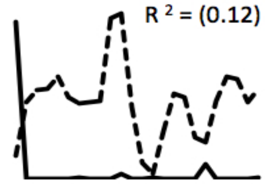
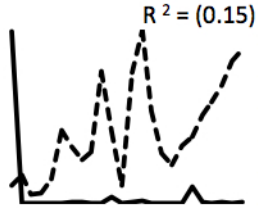
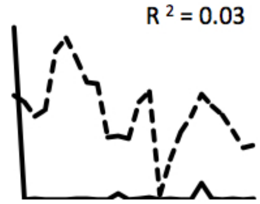
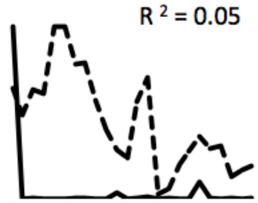
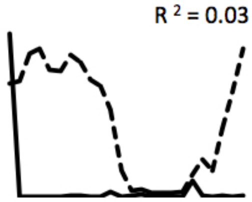
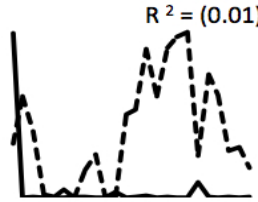
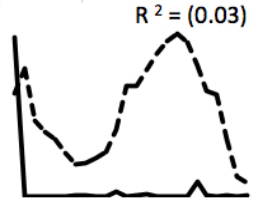
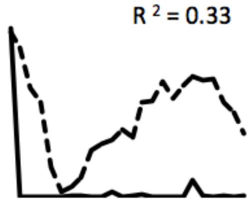
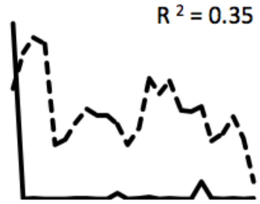
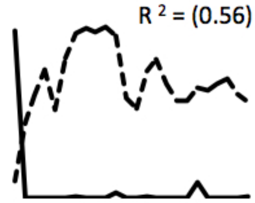
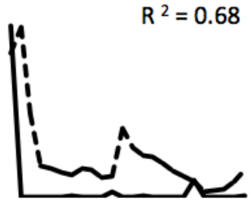
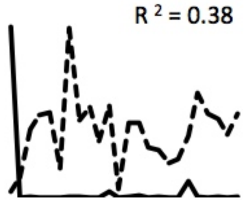
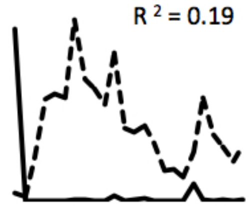
Measure of power (dashed lines)	**Top country's percent of total, vs. battle deaths (solid line)**	**Minimum deviation from 1.0 log-log distribution, vs. battle deaths (solid line)**	**Overall deviation from 1.0 log-log distribution, vs. battle deaths (solid line)**
Energy production	 $R^2 = 0.67$	 $R^2 = 0.54$	 $R^2 = 0.39$
GDP	 $R^2 = 0.10$	 $R^2 = 0.41$	 $R^2 = 0.77$
CINC score	 $R^2 = 0.64$	 $R^2 = (0.18)$	 $R^2 = 0.01$
Military expenditure	 $R^2 = (0.47)$	 $R^2 = 0.45$	 $R^2 = 0.58$
Iron & steel production	 $R^2 = 0.62$	 $R^2 = (0.27)$	 $R^2 = (0.21)$
Energy consumption	 $R^2 = (0.04)$	 $R^2 = 0.10$	 $R^2 = 0.00$
Energy surplus	 $R^2 = 0.12$	 $R^2 = 0.00$	 $R^2 = 0.05$

Table 6: Concentration of power vs. battle deaths (initiated), 1980-2003 (longitudinal)

Measure of power (dashed lines)	**Top country's percent of total, vs. battle deaths (solid line)**	**Minimum deviation from 1.0 log-log distribution, vs. battle deaths (solid line)**	**Overall deviation from 1.0 log-log distribution, vs. battle deaths (solid line)**
Energy production	$R^2 = 0.22$ 	$R^2 = 0.05$ 	$R^2 = 0.00$ 
GDP	$R^2 = 0.00$ 	$R^2 = 0.04$ 	$R^2 = 0.20$ 
CINC score	$R^2 = 0.09$ 	$R^2 = (0.25)$ 	$R^2 = (0.12)$ 
Military expenditure	$R^2 = (0.15)$ 	$R^2 = 0.03$ 	$R^2 = 0.05$ 
Iron & steel production	$R^2 = 0.03$ 	$R^2 = (0.01)$ 	$R^2 = (0.03)$ 
Energy consumption	$R^2 = 0.33$ 	$R^2 = 0.35$ 	$R^2 = (0.56)$ 
Energy surplus	$R^2 = 0.68$ 	$R^2 = 0.38$ 	$R^2 = 0.19$ 

Of these three most responsive indicators (energy production, energy surplus, and GDP), single-power concentration of energy surplus is the most strongly associated with the intensity of wars initiated while a balanced inequality or stable hierarchy of concentrated energy production and GDP shows the most consistent association with lower intensity wars.

CINC scores and GDP both are strong measures of national power given that both exhibit the highest overall fitness to a power-law hierarchy at any given time. In the case of CINC scores, this is probably because of the method by which they are constructed, which is to compute countries' relative power as a single ratio taken from a composite of several indicators of capability. In the case of GDP, a similar dynamic is at work whereby a composite of indicators is couched in relative rather than absolute terms. Both measures are by design reflective of relative position and therefore are expected to fit a distribution that in the physical world ultimately results from cumulative advantage and efficiency-maximizing political and economic processes. But both are nevertheless relatively crude and weak indicators of barometric war pressures in the world system precisely because they draw on composites and contain self-referential variables within variables, no one of which can adequately capture what is physically going on in the substrate of power competition.

In the case of CINC scores, for example, the only measure of energy as a source of power is energy consumption, which does not reflect indigenous capacity or long-term potential but only a country's macroeconomic energy demand at any given time. Other CINC subcomponents such as iron and steel production, as well as military expenditure, are ultimately only derivatives of more fundamental economic capacities like primary energy production.

GDP as a measure of national power has similar issues, in that it fluctuates with nominal changes in measurement and national balance sheets (MacDonald and Parent, 2011). Furthermore, GDP and energy production levels have become decoupled in recent decades, with GDP outpacing energy production to a degree that reveals how much of the non-real or at least non-material economy increasingly is included in the measurement. To borrow from E.H. Carr, where GDP and CINC scores are excellent measures of what is going on in the *superstructure*, only energy production and surplus can tell you what is literally fueling those processes at the *base* (1981). That matters because, for all the influence of political intelligence and financial markets, missile systems, carrier groups, littoral combat ships, mechanized ground forces and aviation assets still run on combustibles, electricity, and reactors, not personnel and organizational ideas.

Conclusion

It's my opinion that a hard-science view of international politics is generally supportive of the theory of hegemonic stability and the otherwise maligned military policy of preponderance. If geopolitics is a physical, metabolic system that can be comprehended as such, it can be manipulated so that we are not bound to the inevitability of epic hostilities observed so far (Morgenthau 1978). At the same time, a cautionary note is in order when examining the effect of specific, disproportionate concentrations of power, or what may be reckless *realpolitik* masquerading as preponderance and stability. While the loss of a concentrated distribution of power is fundamentally destabilizing, the excess of it may be as well. Consider the behavior of both Japan, and the U.S. in response to Japan, in the 1930s, when not just Japanese regional ambitions but also early U.S. attempts to choke off Japanese access to energy markets resulted in avoidable political catastrophes that had been largely glossed over by the narratives of empire and liberal order, respectively (Snyder 1991; Breslin 1976).

But as stated at the outset, my purpose is not to make policy recommendations or resolve grand debates about polarity and power politics. This study began with the simple question, what is the best measure of military potential, if this is synonymous with national power? The answer has to be dyad-agnostic, looking not at individual contests but rather at the systemic constraints out of which those contests emerge, whether they involve status-quo challengers or status-quo defenders as the instigators. Economic measures like GDP and energy consumption are simply inadequate to describe such constraints without resort to an infinity of qualifiers involving trade balances and so forth. And less contingent measures like steel production lose in comprehensiveness whatever they gain in concreteness. Energy production and energy surplus satisfy the requirements of both physicality and universality because they independently measure what is out there to be controlled by the competitors using the one capability that is by definition at the source of all other capabilities. The best competitors will be the ones who understand and are in a position to use these measurements.

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