THE ENDURING THREAT OF A LARGE INTERSTATE WAR

Aaron Clauset | 2017

An OEF Research Discussion Paper

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Cover Image: An unarmed ICBM test in 2016. Photo by US Air Force.
Inside page: The “Peace Side” of the Standard of Ur mosaic; public domain.

EXECUTIVE SUMMARY

Since 1945, there have been relatively few large interstate wars, especially compared to the preceding 30 years, which included both World Wars. The implications of this pattern, sometimes called "the Long Peace," remain highly controversial. Is this an enduring trend toward peace? Or is it temporary, representing a fluctuation within an otherwise stable system of conflict? Answering this question has remained difficult because of substantial evidence supporting both perspectives and the enormously variable nature of war. Here, advanced statistical methods are employed to examine the hypothesis of there being a trend toward peace in three conflict variables related to interstate wars between 1823 and 2003: the sizes of wars, the delay between onsets of new wars, and the production rates of wars of different sizes over time. Across these variables, this analysis finds little evidence for an overall trend toward peace, and finds that the observed statistical patterns are not inconsistent with a stationary conflict-generating process. Moreover, this analysis shows that the size of the Second World War is not anomalous given the heavy-tailed distribution of war sizes, that war sizes and delays between wars in the post-war period are statistically indistinguishable from those prior to the Second World War, and that the time-dependent production rates of wars of all sizes, both before and after the Second World War, fall within expectations for a stationary process. However, in agreement with a broad range of evidence indicating a decline in violence since 1945, the analysis finds that the post-World War II period does in fact exhibit a markedly lower production rate for the very largest interstate conflicts, which is balanced by an increased likelihood of smaller conflicts. Because of the rarity of interstate wars, this trend would need to continue for 100–150 more years in order to reliably conclude, on the basis of war data alone, that it was not a long transient under a stationary process. That is, the decline in large-scale interstate violence since 1945 is measurable, but its status as a trend or fluctuation remains uncertain without reference to other evidence. These results illustrate that the Long Peace may be substantially more fragile than proponents believe, and it will be crucial to continue to support that peace through policy and to support research efforts to identify the underlying mechanisms that shape trends in conflict over the long run.

TABLE OF CONTENTS

WHETHER—AND WHAT—TRENDS EXIST IN VIOLENT CONFLICT

Arlington National Cemetary; U.S. Air Force photo.

Looking out over the next 100 years, should we expect to see another international conflict that kills tens of millions of people, as the Second World War did in the twentieth century? What is the 100-year probability of such an event? What are the underlying social and political factors that drive this probability higher or lower over time?

These questions represent a mystery at the center of understanding international conflict[1] and the arc of modern civilization. Are there trends in the frequency and severity of wars between nations, or, more controversially, is there a trend specifically toward peace? If such a trend exists, what factors are driving it? On the other hand, if no such trend exists, what processes fundamentally govern the likelihood of war, and why is that likelihood stable despite changes in so many other aspects of the modern world? Scientific progress on these questions would shed considerable light on whether the twentieth century's great efforts to prevent another major war have been successful, or whether the lack of another such conflict has been blind luck or a temporary hold. Moreover, scientific progress would help quantify the odds of a similar event occurring over the next 100 years.

Early debates on whether—and what—trends exist in violent conflict, and particularly in interstate wars, tended to focus on trends in the causes of war. Some researchers argued that the risk of war is constant and fundamentally inescapable, while others argued that warfare is dynamic and its frequency, severity, and other characteristics depend on malleable social and political processes.[2] More recent debates have focused on whether there has been a real trend toward peace, particularly since the end of the Second World War,[3] with mechanistic arguments focusing on how peace-time alliances,[4] economic ties and international organizations,[5] and the spread of democracy[6] specifically reduce the risk of war.

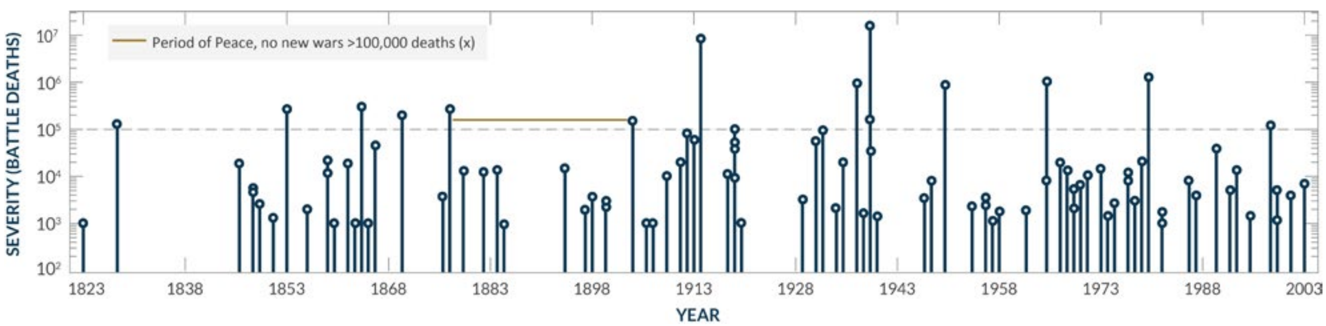
Resolving these debates has been difficult because there are multiple ways to formalize the notion of a trend in conflict.[7] For instance, should the focus be only on international conflicts, or should it include other types of conflict, such as civil wars, peacekeeping missions, or merely the use of military force? Should only conflicts among major powers be considered, or only those between geographically close nations, or should all nations be included? What conflict variables should be considered? How should we account for non-stationary characteristics of conflict—e.g., the changing number of states and relations among them, which have increased by nearly an order of magnitude over the past 200 years; the increasing frequency of asymmetric or irregular conflicts; the use of insurgency, terrorism, and radicalization; improvements in the technology of war; etc.? Different answers to these questions can lead to opposite conclusions about the existence or direction of trends.[8]

Conflict data comprise a sparse time series of inherently rare and often only roughly measured events produced by an evolving geopolitical system. This complicates efforts to reliably distinguish genuine trends from chance fluctuations.

Compounding the definitional issues is the lack of good data for most choices of conflict variables. Ideally, data should be systematic in coverage, unbiased and precise in measurement, and plentiful enough to provide good statistical power against alternative hypotheses. In reality, conflict data comprise a sparse time series of inherently rare and often only roughly measured events produced by an evolving geopolitical system. These characteristics somewhat complicate efforts to reliably distinguish genuine trends from chance fluctuations.

In this article, evidence is quantified for or against trends in the frequency or severity of conflicts, and in the durations of periods of peace between conflicts, for interstate warfare since 1823. In this setting, a trend toward peace could appear as a tendency toward less severe wars (fewer deaths), or as a tendency toward longer periods of peace between the onsets of new wars of different severities. These questions are investigated using the Correlates of War interstate conflict dataset[9] (Figure 1), which provides the most comprehensive coverage available for 180 recent years of conflict with few artifacts and relatively low measurement bias. This research design allows achievement of conclusive results on the question of whether there is a trend toward peace in the frequency and severity of modern interstate warfare.

Figure 1: Interstate Conflict Data Time Series



The Correlates of War[10] time series shows both severity and onset year for the 95 conflicts in the period 1823–2003. A "period of peace" is defined as a timespan in which no new wars with severity at least began. A solid gold line indicates one such peace, lasting 27 years, for *X* = 100,000 battle deaths (dashed horizontal line).

SETTING THE STAGE

A trend in the frequencies or sizes of wars is inherently a statement about changes in the likelihood of rare events. Efforts to test this hypothesis typically focus either on the underlying mechanisms that produce wars or on the underlying distributions the events are drawn from. In either case, it is common to focus on the severities or the sizes of wars over time, and how war size depends on conflict covariates such as the characteristics of the involved nations, the circumstances that preceded the conflict's onset, the technology used, etc. For the analysis performed here, there are four particular advances that set the stage.

A first advance came in the early twentieth century through the seminal work of the English polymath Lewis Fry Richardson,[11] who found that the sizes of wars worldwide exhibit a statistical pattern called a heavy tail, in which the largest wars are many orders of magnitude larger than a "typical" war, at least as measured in terms of battle deaths. More specifically, Richardson argued that war sizes follow a precise pattern, called a power-law distribution, in which the probability that a war kills *x* people is $\Pr(x) \propto x^{-\alpha}$, where $\alpha > 1$ is called the "scaling" parameter.

Sizes of wars worldwide exhibit a statistical pattern called a heavy tail, in which the largest wars are many orders of magnitude larger than a "typical" war.

A power law is a probability distribution with unusual mathematical properties.[12] One property in particular is important for the analysis here: when observations are generated by a power law, estimates of even simple summary statistics, such as the mean or variance, can exhibit large fluctuations that can resemble a trend. Which statistics fluctuate, and by how much, depends on the value of the scaling parameter, with the most extreme fluctuations occurring for $1 < \alpha < 3$.

The appearance of a power law in some empirical quantity can indicate the presence of exotic underlying mechanisms, including nonlinearities, feedback loops, and network effects,[13] although not always,[14] and power laws are believed to occur broadly in complex social, technological, and biological systems.[15] For instance, the intensities or sizes of many natural disasters, including earthquakes, forest fires, and floods, are well described by power laws,[16] as are the sizes or severities of riots and terrorist attacks.[17]

> *When observations are generated by a power law, estimates of even simple summary statistics can exhibit large fluctuations that can resemble a trend.*

A second advance came from the development of high-quality and comprehensive data on wars. Within conflict research, one of the most well-regarded and well-analyzed data sources for war sizes and other covariates comes from the Correlates of War project,[18] which built on early work by Small and Singer.[19] The analysis here utilizes the Correlates of War data on interstate conflicts, which provides comprehensive coverage of the 95 distinct conflicts over the 1823–2003 period. These data span an enormous expansion of the international system, one in which the number of recognized states grew from roughly 25 to nearly 200, and span the post-World War II period, during which any evidence supporting the claim of a trend toward peace should appear.

A third advance came via the development of more rigorous methods for characterizing the shape of the size distribution of wars. Heavy-tailed quantities like war sizes pose special difficulties for statistical analyses because of their large fluctuations. These fluctuations are greatest in the upper tail, which governs the frequency of the largest and rarest events, meaning that the data are sparsest precisely where we would like the greatest precision in order to detect a trend. Partly because of newfound interest in power-law and other heavy-tailed distributions in applied physics, computer science, and biology, more rigorous methods have recently been developed for characterizing the shape of heavy-tailed distributions in empirical data,[20] for comparing models of the upper tail,[21] and for principled statistical forecasting.[22]

> *The broader debate on the existence of a genuine trend toward peace after the Second World War can be viewed as a long-running debate between liberal and realist perspectives.*

Finally, the broader debate on the existence of a genuine trend toward peace after the Second World War can be viewed as a long-running debate between liberal and realist perspectives.[23] Liberalism argues, from multiple lines of empirical evidence, some spanning hundreds or even thousands of years (for example, see Pinker[24]), for a broad and general decline in human violence and a specific decline in the likelihood of war, especially between the "great powers." In contrast, realism also argues from empirical evidence, some of which also spans great lengths of time (for example, see Cirillo and Taleb[25]), for the absence of any discernible trend toward peace.

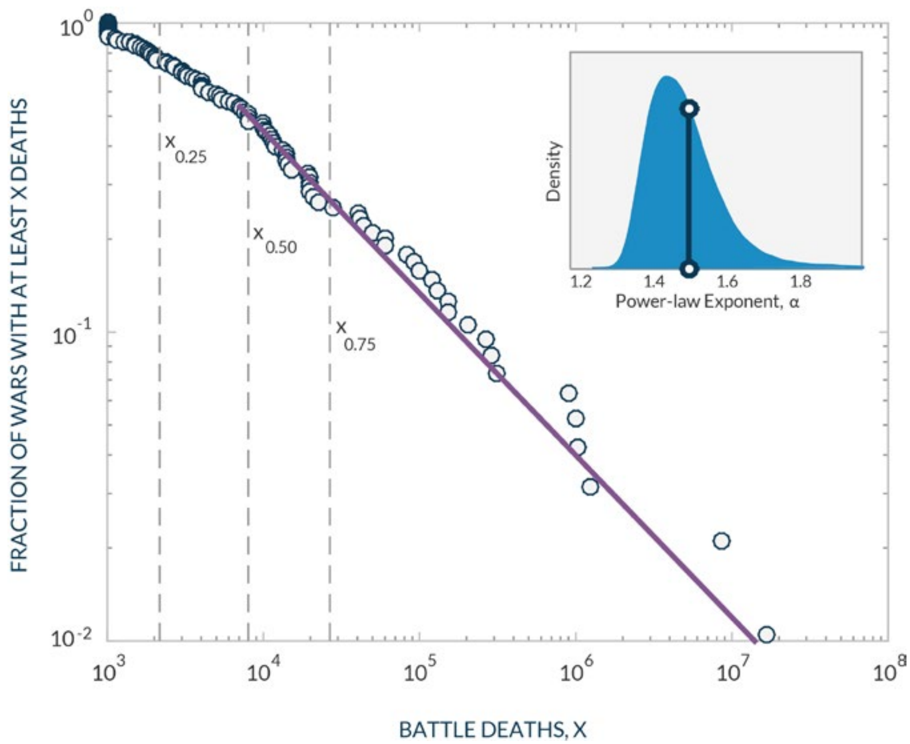
The terms of this debate are somewhat orthogonal to the focus here (see Briggs[26] and Spagat[27]) except for two key points. First, the debate rests on a disagreement about what null model should be used to interpret empirical conflict data. And second, the heavy-tailed structure of the size distribution of wars, with its large fluctuations, can naturally produce long transient patterns of low-severity conflicts or even the absence of conflicts (periods of peace), and these fluctuations make it difficult to clearly distinguish genuine trends from long but transient behavior.

Although some conflict datasets[28] cover substantially longer periods than the Correlates of War data, their coverage prior to 1800 is likely incomplete and biased. Historical accounts of ancient conflicts are likely substantially less accurate and their coverage of all conflicts less unbiased the further back in time we look. As a result, it is unclear whether the increased sample size offered by such datasets can compensate for the unknown biases they include relative to the smaller but more reliable Correlates of War data. In the analysis here, the conservative choice was made to use a higher-quality dataset at the cost of lower statistical power for distinguishing trends from fluctuations, and the focus is on the realist null model—that of a stationary conflict-generating process.

THE SIZES OF WARS

Richardson's original analysis of war sizes used relatively loose statistical methods.[29] Since then, more rigorous methods and better data have confirmed his conjecture that war sizes are plausibly power-law distributed (Figure 2). These methods allow for a precise estimate of the maximum likelihood scaling exponent α to locate the minimum size x_{min} above which the power-law behavior holds, and to quantify various kinds of statistical uncertainty in the quality of the model and its plausibility as a data-generating process.[30]

Figure 2: Severity Distribution for Interstate Wars, 1823–2003



Severity distribution with the best-fitting power-law model of the largest-severity wars (parameters: $\hat{\alpha} = 1.53 \pm 0.07$ and $\hat{x}_{min} = 7061.$). The inset shows the bootstrap distribution of estimated parameters $Pr(\hat{\alpha})$ with the maximum likelihood estimate (black line), the breadth of which illustrates the substantial uncertainty in the precise distribution for the frequency of large wars.

Focusing on patterns in war sizes necessarily omits other characteristics of individual conflicts, and of the world as a whole, which may contain independent signals about trends in conflict. For instance, characterizing patterns in war sizes alone leaves no account of changes in the declared reasons for conflicts, the manner in which conflicts are fought, their aftermath, the details of their settlements, their relations to other conflicts past or future, the number of nations worldwide, etc. On the other hand, one benefit of ignoring these varied characteristics is that they may not, in fact, matter for the question of identifying an overall trend in wars. In addition, focusing on war sizes alone substantially simplifies the range of models to consider, which may improve the likelihood of detecting some underlying trend.

In the approach here, it is assumed that wars are drawn from a single, global conflict-generating process, and an effort is made to identify whether it exhibits non-stationary patterns that are consistent with a trend toward or away from peace. More specifically, the focus here is on two quantities: war severity (size) as measured by absolute battle deaths, and the durations of periods of peace, defined as the number of years between onsets of wars with severity at least some *X*. There is also a focus on trends in the joint distribution of war severities and peace durations. The first section covers a set of tests for trends in the severity of wars over time. The second covers tests for trends in the durations of peace over time. The third section covers tests for trends in the durations of peace over time, and finally, the test for trends in the joint covariance of war severities and peace durations.

The Distribution of War Sizes

The maximum likelihood parameter for a power-law model of the sizes of wars in the Correlates of War interstate conflict data is $\hat{\alpha} = 1.53 \pm 0.07$ for wars with severity $x \geq x_{min} = 7061$. A bootstrap procedure allows a numerical estimation of an underlying distribution of model parameter estimates, which provides a simple assessment of the quality of the maximum likelihood model (Figure 2 inset). For this distribution, 95% of its density falls within the interval $\alpha \in [1.37, 1.76]$, with a median value of $\alpha = 1.49$. This value is very close to the maximum likelihood estimate $\alpha = 1.53$, indicating a reasonably good fit of the model to the data.

Under an appropriately defined statistical hypothesis test,[31] this model of the distribution's upper tail is a statistically plausible data-generating process ($p_{KS} = 0.78 \pm 0.03$), meaning that the observed data are as a group indistinguishable from an iid draw from the fitted power-law model. This result is consistent with past analyses of war intensities (a population-normalized measure of war size) over a similar period of time, which found the power-law model to be both statistically plausible and at least as good a model of the data as alternative heavy-tailed distributions, including a power-law distribution with an upper exponential cutoff.[32]

The statistical plausibility of the power law as a model of the data-generating process for the sizes of wars indicates that a stationary process whose form does not vary over time is not inconsistent with the observed data, at least under this type of analysis. This fact is in agreement with the realist argument that there is no evidence for a trend toward or away from peace.

There are several reasons, however, that this conclusion should not be embraced too quickly. The most obvious of these is that the sample size is relatively small, which reduces the ability to distinguish genuine patterns from sampling fluctuations within the deviations between the fitted model and the overall data. There very well could be a trend in these data, but the natural fluctuations are too large to detect it in a dataset this small, a point that will be returned to subsequently.

Putting aside the sample-size issue, the fitted power-law model itself only covers the upper 54% of the distribution. As a result, it is only a plausible model for the frequencies of the largest wars, with nearly half of all wars falling outside the range covered by the model. This incomplete coverage opens up the possibility that the sizes of small wars may follow a different pattern than the sizes of large wars do. A full treatment of the possibility of a trend in the severity of wars must therefore account for both the small and large ends of the distribution.

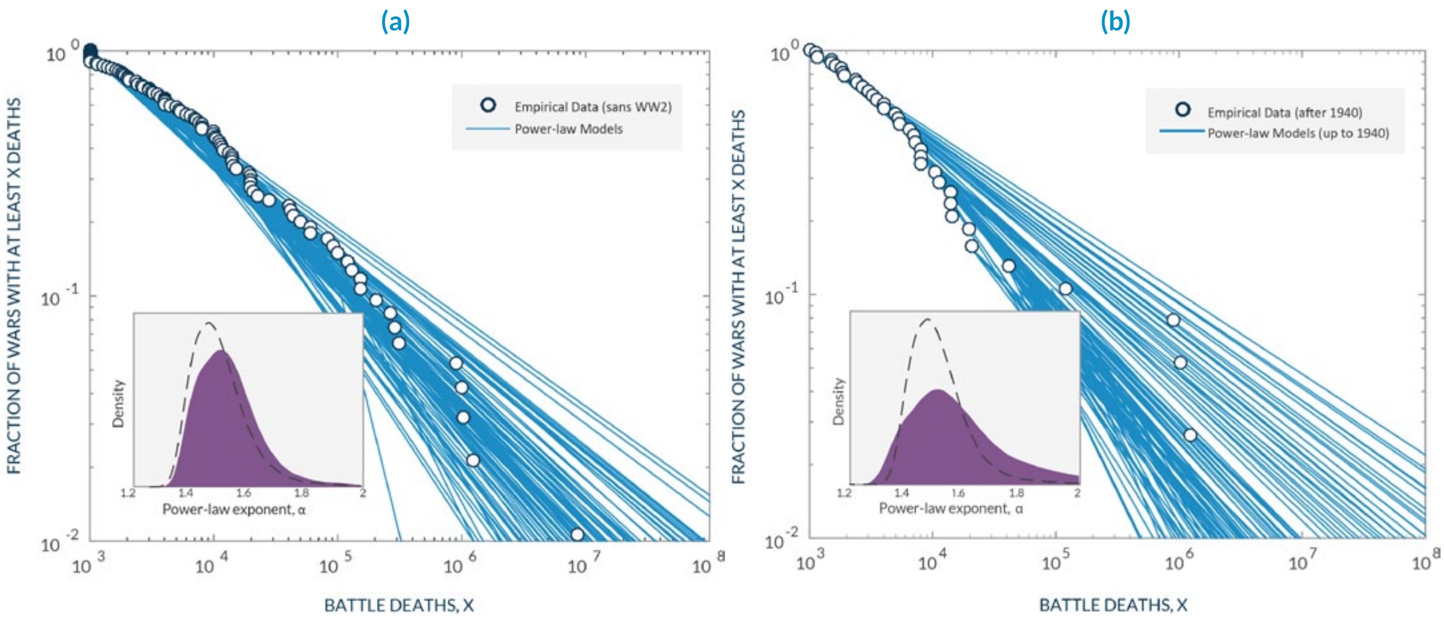
Similarly, the specific timing of war onsets may reveal subtle patterns, for instance, if the deviations from the power-law model are non-uniform across the 1823–2003 period. In the debate around whether a trend toward peace exists, the Second World War is usually identified as a likely point of change in the characteristics of the underlying conflict-generating process, and thus many subsequent analyses here will consider differences between pre- and post-World War II conflicts.

The Likelihood of a Large War

To better evaluate the reliability of the stationarity hypothesis identified above, two tests based on statistical forecasting can be conducted. Each test uses a bootstrapping procedure on the empirical data to fit an ensemble of statistical models from which a probabilistic estimate of the likelihood of a large war can then be derived.[33]

The first test estimates the likelihood of observing a war at least as large as the Second World War, which has a recorded severity of x_* = 16,634,907 battle deaths, and considers whether this likelihood is small or large.[34] This test is mainly sensitive to whether the size of the largest war is plausibly a statistical outlier relative to the overall war-size distribution. Following Clauset and Woodard,[35] if its likelihood is non-trivial, then we may conclude that the occurrence of the largest war follows the same statistical pattern as the frequencies of smaller wars within the modeled range of sizes.

Figure 3: Power-Law Tail Models of **(a)** Conflict Sizes, Excluding WW2, and **(b)** Pre-WW2 Conflict Sizes



Power-law tail models fitted to bootstrap samples of (a) all conflict sizes (1823–2003) but with the WW2 event removed, and (b) pre-war conflict sizes (1823–1940; events prior to WW2). In (b), the pre-war models (1823–1940) are compared with the post-war conflict sizes (1941–2003), showing good agreement. Insets plot the bootstrap distributions of $\hat{\alpha}$ for each set of tail models, showing little change relative to the distribution estimated from the full dataset (dashed black line).

After removing the x_* event from the complete dataset, the next step is to construct an ensemble of power-law models that are each fitted independently to a bootstrap sample of the remaining 94 war sizes. Figure 3a shows such an ensemble of fitted tail models, along with the size distribution for the 94 war sizes, which fall well within the "cloud" of model lines. Similarly, the distribution of estimated model parameters shifts only slightly toward larger values, meaning distributions that are slightly less heavy-tailed as a result of removing the largest event (Figure 3a inset).

Across the ensemble of models, the average probability of observing at least one event out of 95 with severity at least x_* is $q = 0.525 \pm 0.002$, and the marginal probability that any particular war (drawn iid) is at least as large as x_*

is $p_* = 0.0092355319$ (a uniform hazard rate). Therefore, the expected number of wars needed to observe one event of size x_* or larger is $1/p_* = 108$. With 95 observed wars over 181 years, war onsets have occurred, on average, every 1.9 years. Thus, the average recurrence time of an event of size x_* or larger is about 205 years, and the size of the Second World War cannot reasonably be considered an outlier with respect to the overall severity distribution of wars since 1823.

The size of the Second World War cannot reasonably be considered an outlier with respect to the overall severity distribution of wars since 1823.

That said, the quantity *q* is only an average, and the expected variance in the arrival times of large wars will be large due to the heavy-tailed distribution of war sizes. As an analogy, consider the sizes of earthquakes, which also follow power-law statistics. There has been substantial scientific and popular interest in estimating the likelihood of another "great" quake in the San Francisco area. The last such event was a magnitude 7.8 quake in 1906, which led to the destruction of about 80% of the city and killed at least 3,000 people. Simple estimates of the waiting time for another such earthquake vary from 80–200 years, and more sophisticated seismological models estimate an average waiting time of 101 years, with 68% of the density falling in the interval 40–162 years.[36] The development of comparable models for interstate conflicts would likely lead to significant advances in both our understanding of the conflict-generating process and the uncertainty that underlies statistical forecasts.

War Severity Over Time

The second test considers whether the distribution of war sizes in the post-war period (after 1940) differs from what we would predict from the pattern of war severities in the pre-war period.

This question is considered in two ways. First, by forecasting the number of wars in the post-World War II period for different orders of magnitude, e.g., 10^3–10^4, 10^4–10^5, etc., and examining how the post-war data differ from these predictions. And second, by visually comparing the distribution of war severities after 1940 with the ensemble of models fitted to the pre-war data. These tests allow us to diagnose whether the observed frequencies of wars of different sizes in the post-war period differ from what we would expect having only seen the pre-war data. If a trend exists, then the observed post-war size distribution should clearly deviate from the ensemble of models fitted to pre-war data.

Testing begins with fitting an ensemble of models to bootstrap samples of the sizes of the 57 wars which had onsets in 1940 or earlier, then computing the average fraction of wars these models predict will occur by order of magnitude and comparing these model-driven forecasts with the observed fraction of the 38 war severities in the post-war period (Table 1).

German invasion of Crete, Second World War. Getty Images

The proportions of wars observed and predicted to fall within each severity class exhibit no simple relationship, and are relatively close in many places. This implies that the war sizes in the post-war period do not deviate dramatically from those of the pre-war period. However, some differences do occur, and these may reflect an underlying trend toward peace. In particular, during the post-World War II period, roughly 7 times fewer moderate-sized wars (battle deaths between 10^5–10^6) were observed than were predicted by the pre-war size distribution, and there were no wars in the largest bins (more than 10^7 battle deaths). It was also observed that there were 1.3 times more small wars (less than 10^4 battle deaths) and 1.7 times more larger wars (between 10^6–10^7) than predicted.

Proportions of wars observed and predicted exhibit no simple relationship. However, roughly 7 times fewer moderate-sized wars were observed than predicted, and there were no wars in the largest bins.

The lattermost statistic should be treated with particular caution as both the observed and predicted fractions at the upper end of the distribution are very small. This tends to amplify the apparent degree of disagreement between a continuous prediction and an empirical distribution derived from a finite sample. The absolute differences (last column in Table 1) show that the observed and predicted numbers are in fairly close absolute agreement, except for the smallest and moderate-sized war bins. Deviations in the lower end of the distribution should be more reliable, suggesting that the sizes of some wars have genuinely been reduced relative to what the pre-war size distribution predicted.

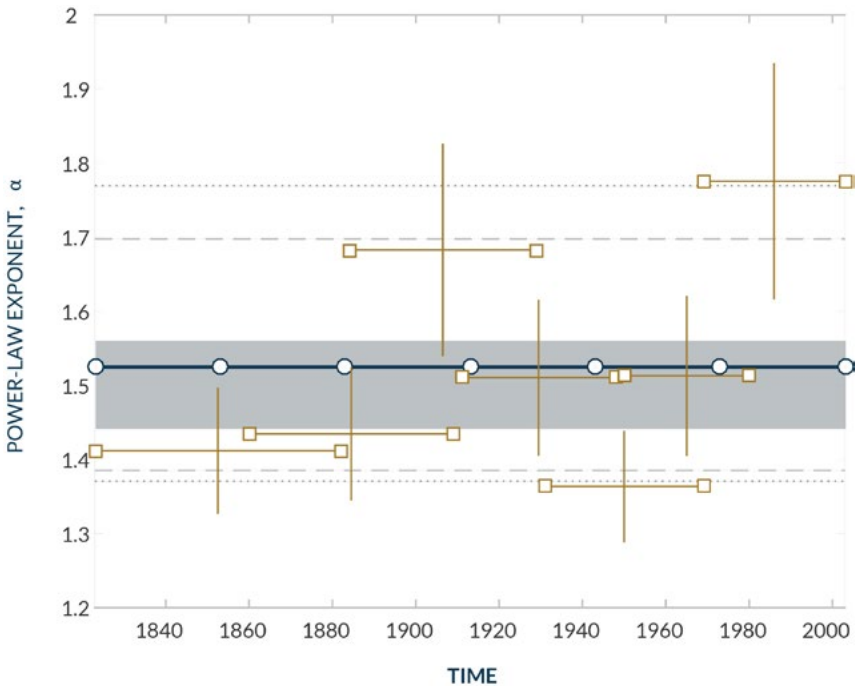
Table 1: Observed & Expected Fractions of War Severities *(by order of magnitude, post-WW2)*

Severity Range	Observed f_{obs}	Expected f_{exp}	f_{obs}/f_{exp}	$f_{obs}-f_{exp}$
10^3–10^4	0.5263	0.3916	1.34	0.135
10^4–10^5	0.3684	0.3673	1.00	0.001
10^5–10^6	0.0263	0.1739	0.15	-0.148
10^6–10^7	0.0789	0.0464	1.70	0.033
10^7–10^8	0.0000	0.0138	—	-0.014
10^8–10^9	0.0000	0.0071	—	-0.007

Visually, however, the ensemble of models fitted to the pre-war data overlaps strongly with the empirical distribution of war sizes in the post-war period (Figure 3b), suggesting that the deviations calculated in Table 1 may be transient fluctuations.

A third, less formal test based on war severities considers how the war-size distribution's shape has varied over time, specifically by dividing the 95 events into overlapping periods of time several decades in length and then fitting a power-law model to the wars which had onsets that fall within each period. The resulting time series of estimated exponents $\hat{\alpha}(t)$ provides a simple assessment of whether the shape of the war-size distribution itself exhibits any non-stationary trends (Figure 4). Because a stationary power-law distribution is a plausible data-generating model of the total dataset, one would expect that the power-law parameter's time series should vary around the stationary model's value.

Figure 4: Estimated Scaling Exponents for Conflicts, 1823-2003



Estimated scaling exponents for events occurring within 7 overlapping periods across 1823–2003, showing non-trivial variability relative to the overall distribution of scaling exponents (fitted to all data at once; solid-gray range indicates the middle 50% of Pr(α), dashed lines indicate the middle 90%, and dotted lines the middle 95%).

Across the 181-year period, the two excursions of $\hat{\alpha}(t)$ above the stationary mean suggest that there were two periods during which conflicts were generally less severe. These excursions occur, perhaps not coincidentally, just prior to the First World War and after about 1970. The variations in $\hat{\alpha}(t)$ suggest that the variability of the war-size distribution may be more complicated than is assumed by a simple iid model and that changes in the shape of the distribution may correspond to genuine periods of peace. The timing of the second period of lower-severity conflicts agrees with the popular hypothesis of there being a genuine but historically recent trend toward peace. However, the fact that a similar period of lower-severity conflicts occurred prior to the First World War, and that it was followed by a period of particularly severe conflicts, suggests that long periods of having more relatively lower-severity conflicts may simply be long transients in a fundamentally stable but highly variable process.

THE DURATIONS OF PEACE

There being a change in the sizes of wars is only one way to formalize the notion of a trend toward peace. A trend could also exist in the time between new conflicts; for example, the time between onsets of new wars could be steadily increasing or could have increased more discontinuously around some particular moment—e.g., the Second World War. In fact, the durations of these periods of peace may be independent of the sizes of the corresponding wars, implying that detecting or failing to detect a trend in one of these variables may say nothing about the existence or shape of a trend in the other.

Here, the test for the existence of trends in the time between new war onsets occurs in two ways. First, we consider the empirical distribution of the durations of periods of peace over the period of 1823–2003; this analysis obtains a simple parametric model of the entire distribution. We then fit this model to the periods of peace prior to the Second World War and compare the results of a simple forecast of the relative frequencies of durations for the post-war period with the observed durations during this period. Finally, a nonparametric test of whether the differences between the duration distributions in the pre- and post-war periods are statistically significant is performed.

The Distribution of Peace Durations

Armistice Day, 1918. Photo by AP Photos.

The empirical distribution of durations of peace across 1823–2003 (Figure 5) exhibits several features worthy of discussion. First, there is a modest amount of density located at $t = 0$, caused by the 14 years (8%) in which more than 1 war onset occurred. In all other years, there were either 0 or 1 new onsets. In the subsequent analyses, these trivial durations are discarded and the focus is instead on periods of peace—during which the world experienced no new onsets—that lasted at least 1 year. Of course, many of these "periods of peace" are not all that peaceful, as wars previously begun may continue. This observation does not change the subsequent analysis here, but it does raise another possibility for detecting a trend toward peace, which is in the duration of conflicts.

Figure 5: Distribution of Periods of Peace, Interstate Wars 1823-2003

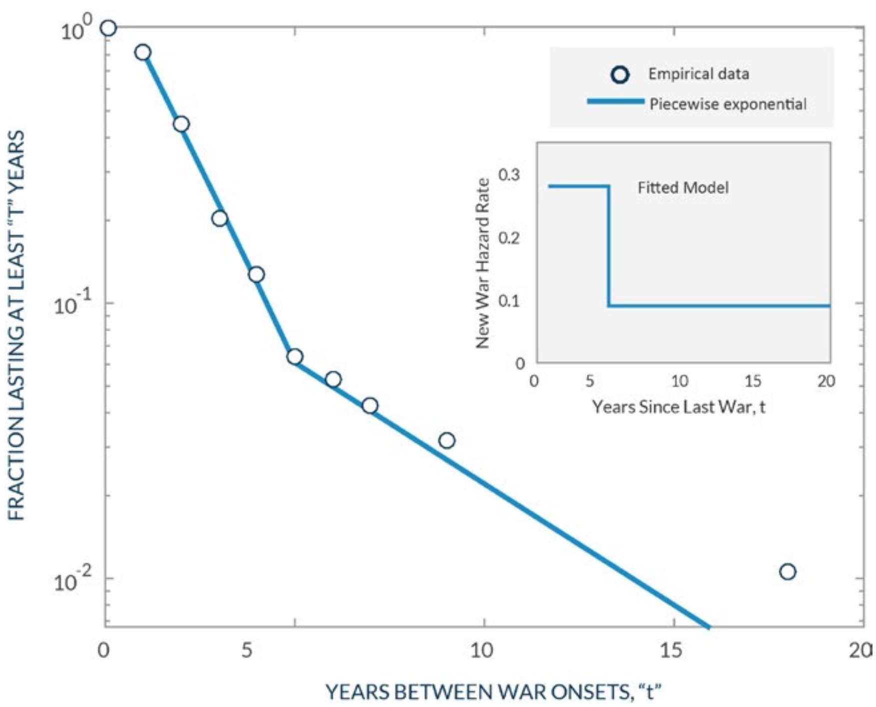


Figure 5: Distribution of periods of peace for interstate wars from 1823–2003, with the best-fitting piecewise geometric model (parameters: $\lambda_1 = 0.603$ for $t \leq 5$ years and $\lambda_2 = 0.203$ for $t > 5$). The inset shows the corresponding hazard rate function for the probability of a new war onset.

A second feature of the durations of peace distribution is an obvious visual "kink" around $t = 5$, in which the distribution above this value decays more slowly than it does below. There are relatively few periods of peace of more than 5 years compared to shorter periods of peace, but these longer periods tend to be much longer than expected given the relative frequencies of shorter periods.

This latter feature, along with the roughly linear shape on a semi-log plot, suggests that a simple piecewise combination of geometric distributions is a reasonable model of these data. In such a model, the probability Pr(*t*) that a period of peace lasts *t* years is

$$\Pr(t) \propto \begin{cases} e^{-\lambda_1 t} & \text{if } 1 \leq t < t_* \\ e^{-\lambda_2 t} & \text{otherwise .} \end{cases}$$

Fitting this model to the observed durations of peace via maximum likelihood yields parameters $\lambda_1 = 0.603$ and $\lambda_2 = 0.203$, under a choice of t_* 5 years (Figure 5).

If a random variable follows a geometric distribution, the parameter λ has a natural interpretation as a constant hazard rate in a simple stochastic stopping process. That is, λ is the probability in each year that a new war will occur, thereby ending that period of peace. In the piecewise geometric model here, there are two such parameters: λ_1 is the annual new-war probability when the peace is years old while λ_2 is the probability when the peace is $t > t_*$ years old. The corresponding new-onset hazard function is thus piecewise constant (Figure 5 inset) with a discontinuity at $t_* = 5$ years, after which the probability of a new war drops by about a factor of 3. Although the discontinuity at $t = 5$ years may seem like a striking pattern, it appears to be merely a transient pattern: all of the durations supporting the λ_2 regime occurred prior to the Second World War, when there were relatively fewer recognized states worldwide.

Peace in the Post-World War II Period

Following this analysis of war severities, we fit the piecewise geometric model of peace durations to the 56 periods of peace that occurred prior to 1940 and use this model to make a forecast for the relative frequencies of different durations of peace compared to the periods of peace in the post-war period. Then those predictions are compared to the observed data in the post-war period. If a trend exists, then the observed post-war duration distribution should clearly deviate from the stationary prediction derived from the pre-war durations.

The observed and predicted proportions of durations of different lengths are relatively close to each other (Table 2). This implies that peace durations in the post-war period do not deviate dramatically from those in the pre-war period, despite there being a substantially larger number of states worldwide. That said, there are some minor differences worth noting. In particular, in the post-war period, the longest-duration peace with no new war onsets anywhere in the world is 4 years. Compared to the shape of the distribution over 1823–1940, the post-war period has a slight overabundance of 2-year and 4-year periods of peace, but an under-abundance of 3-year periods.

Peace durations in the post-war period do not deviate dramatically from those in the pre-war period, despite there being a substantially larger number of states worldwide.

Table 2: Observed & Expected Fractions of Durations of Peace for the Post-World War II Period

Duration (years)	Observed f_{obs}	Expected f_{exp}	f_{obs}/f_{exp}	$f_{obs} - f_{exp}$
1	0.4839	0.4576	1.06	0.026
2	0.3226	0.2435	1.32	0.079
3	0.0968	0.1296	0.75	-0.033
4	0.0968	0.0689	1.40	0.028
5+	0.0000	0.1004	—	-0.100

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Supporting this conclusion that no observable trend exists in the durations of periods of peace, a nonparametric two-sample Kolmogorov-Smirnov test finds that the deviations between the pre- and post-war duration distributions are not statistically significant ($D^* = 0.0893$, $p_{KS} = 0.99$).

It is still possible that a trend toward peace could involve the joint distribution of war severity and peace duration.

Both of the above analyses treated conflicts as equivalent in terms of demarcating a period of peace, and found evidence supporting a conclusion that the time between new war onsets is stationary and thus does not exhibit a clear trend toward peace. But not all conflicts are the same, and it is still possible that a trend toward peace could involve the joint distribution of war severity and peace duration.

WAR AND PEACE

A third possibility for a trend in war is that the rate of war onsets varies by the eventual size of the war. Hence, considering one without the other may conceal a subtle pattern that violates the stationarity hypothesis. For instance, it is often noted that the post-war period has had relatively fewer very severe conflicts than did the period that ended with the Second World War.

To investigate this possibility, the first step is to consider the timing of war onsets over the period 1823–2003 for different groups of war sizes and investigate the relative variability in the timing of these wars, then conduct two tests of the stationarity hypothesis using these time series. In each test, the onset year of each empirically observed war is kept fixed but its observed severity is replaced with a simulated value drawn either (i) iid with replacement from the empirical data (a bootstrap of the severities), or (ii) iid from a semi-parametric model of the empirical severity data, using our ensemble of tail models to generate event severities in the tail and drawing from the empirical distribution for severities below the tail. Finally, we extrapolate post-war trends in war onset rates by war size in order to estimate how long the post-war pattern would need to hold in order to falsify the stationarity hypothesis.

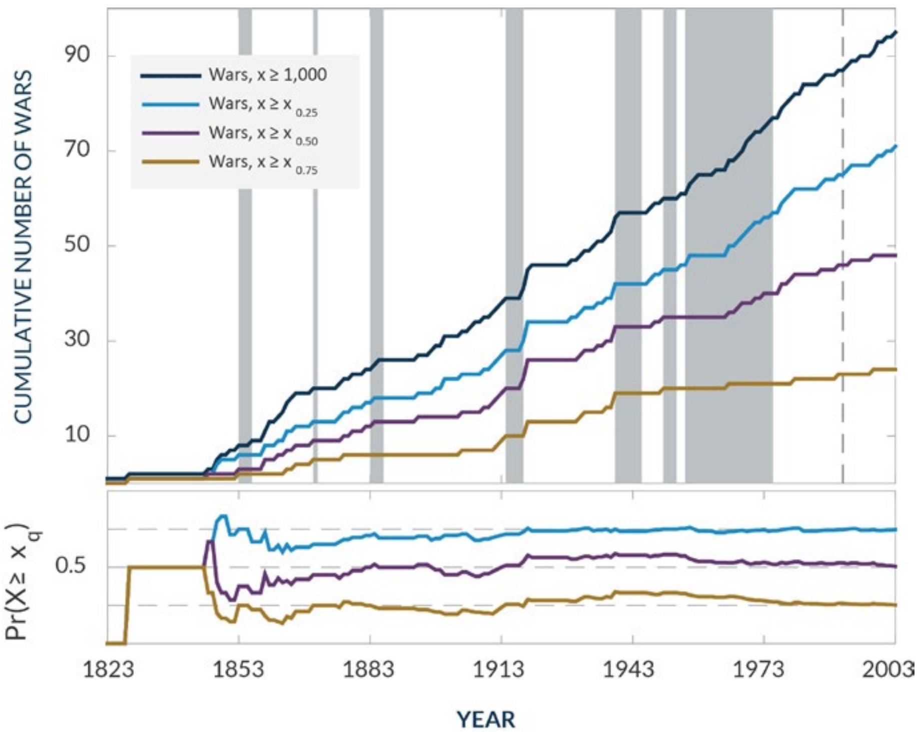
Variability in Onset Rates by War Size

A useful way to represent the timing of war onsets of different sizes is via the cumulative number of wars with severity at least x_q where q denotes a quantile of the war-size distribution. The average production rate is then simply the slope of this cumulative function (Figure 6). Over the 1823–2003 period, the production rate of wars of any severity remained fairly stable, with one new war beginning every 1.91 years, on average, with a standard deviation of 2.40 years.

Because larger wars are less frequent than smaller wars, the production rate for wars with severity $x > x_q$ must be lower than for some $x_{q'} < x_q$. In a stationary process, the variability around the average delay between events does not itself vary with war size. In contrast, if the relative variability increases as we consider progressively larger conflicts, then larger wars tend to cluster together in time, with longer periods of peace between them.

This possibility can be quantified by calculating the delay variable's coefficient of variation $c_v = \hat{\sigma}/\hat{\mu}$, which measures the sample variability of a quantity relative to its sample mean, for groups of wars with progressively greater severity. As a reference point, for all wars, we calculate $c_v = 1.26$. As we consider only those wars with severity above some level, we observe similar values of $c_v = 1.19$, 1.11, and 1.03 for the delays between war onsets for severity thresholds $x_{0.25}$, $x_{0.50}$, and $x_{0.75}$ respectively (Figure 6).

Figure 6: Cumulative Number & Fraction of Wars Over Time



Upper panel: the cumulative number of wars over the 1823–2003 period for wars overall (navy blue), and for wars with severity above the top three quartile values (light blue, purple, gold). Shaded regions indicate the spans of a selection of significant wars for reference. Lower panel: The cumulative fraction of wars over time, for the same thresholds in the upper panel, showing relatively stable proportions.

This consistent pattern in the coefficients of variation for groups of progressively larger wars suggests that periods of peace tend to be distributed relatively evenly across time, which supports the hypothesis of an underlying stationary process. On the other hand, the cumulative functions clearly show that both wars and periods of peace certainly do cluster somewhat together over time (Figure 6). This clustering, however, is correlated across war sizes and seems to reflect the influence that the occurrence of a major conflict, such as the First or Second World War, has on the production of wars of all severities that occur directly after it.

Focusing on the most severe wars alone ($x \geq x_{0.75}$ in Figure 6), the data suggest a possible slowdown in the production of these most severe conflicts during the post-war period, compared to either the production of smaller conflicts in any period or the production of same-sized conflicts in the pre-war period. This type of pattern would also qualitatively agree with the analysis of war sizes here, which suggested that the upper tail of the severity distribution may have thinned out in the post-war period.

There are longer periods of peace between the most severe conflicts after World War II, but shorter periods between smaller conflicts.

To quantify this decrease in the production of the most severe conflicts after the Second World War, the data are split into conflicts before and after 1940, and then split into the upper 25% and lower 75% (quantile values estimated from the full data). After 1940, a new conflict in the most-severe group occurs on average every 12.0 years, while the average delay for all other conflicts is 1.9 years (a ratio of 6.3 smaller conflicts per large event). In contrast, before 1940, the average delays are 6.2 years and 3.2 years (1.9 smaller conflicts per large event). That is, there are longer periods of peace between the most severe conflicts in the post-war era, but shorter periods between smaller conflicts.

The time period of 1914–1940 was particularly conflict-prone, and excluding these conflicts from the above analysis yields average delays between conflicts before 1914 that are much closer to the post-1940 values: 10.6 years between the most severe conflicts compared to 3.1 years for all other conflicts (3.4 smaller conflicts per large event). In other words, many of the largest events do tend to cluster together over a modest period of time, and the production rate of large events outside of this period appears much lower.

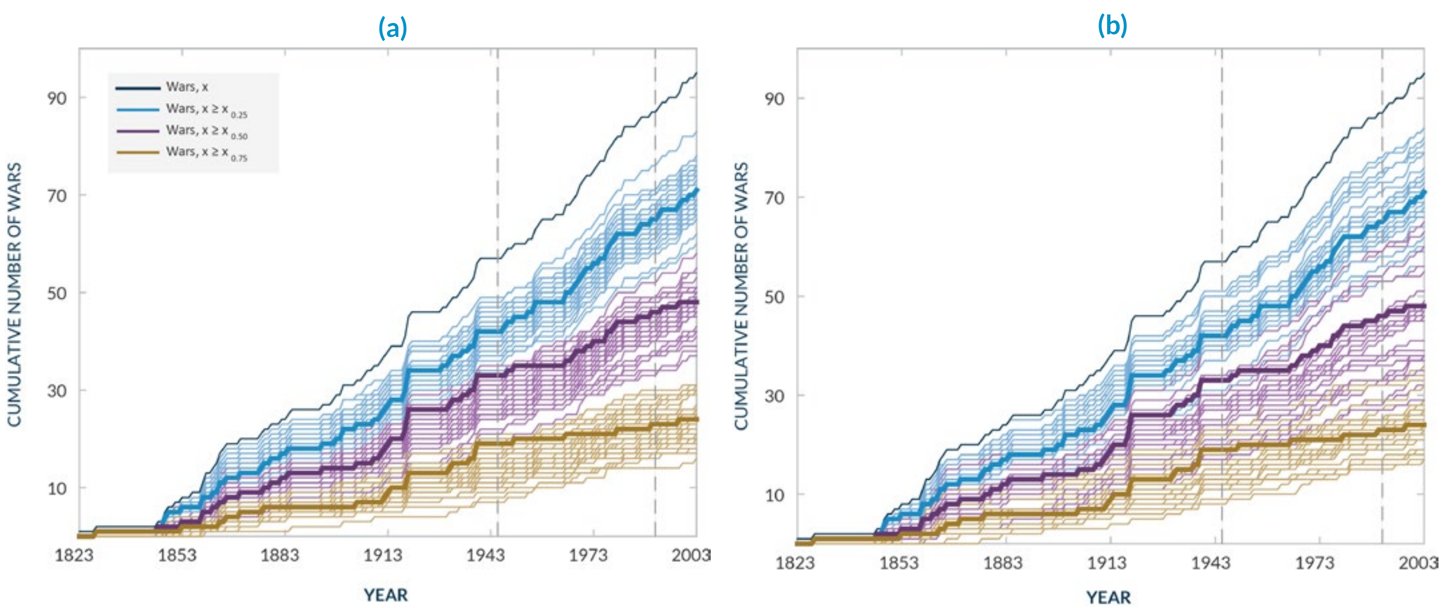
Trend or Fluctuation?

The post-war pattern of there being fewer very severe conflicts and longer delays between them could be a genuine trend, or it could be a fluctuation from a highly variable data-generating process.[37] Distinguishing between these possibilities requires an appropriate null model of a stationary process under which the likelihood of the observed post-war pattern in the relative production rates of different-sized conflicts can be calculated.

There are many possible ways to parameterize such a model, and here we consider two. In both, the empirically observed onset dates are kept fixed and synthetic conflict sizes are drawn iid from one of two models of stationarity for war sizes. For each such simulated time-series of conflicts, we then tabulate the cumulative production curves for the three size quantiles $x_{0.25}$, $x_{0.50}$, and $x_{0.75}$. An ensemble of these curves provides a null distribution for the stationary hypothesis against which the empirically observed production curves may be compared.

In the first model, for each war, a war size is chosen uniformly at random, with replacement, from the empirically observed set of war sizes; i.e., the war sizes are bootstrapped. This approach is similar to a permutation test, but accounts for slightly more underlying variability. In the second model, a war size is chosen semi-parametrically, using the ensemble of estimated war-size distributions, which have power-law tails. This approach allows war sizes to be generated that are larger than any observed in the empirical data, and thus accounts for more underlying variability in the conflict-generating process.

Figure 7: Cumulative Counts of Wars by Severity



The cumulative counts of wars by different severity quartiles, along with synthetic cumulative counts derived from two null models, which replace the observed severities with (a) a bootstrap draw from the empirical distribution of severities, or (b) a draw from a semi-parametric model of the severity distribution (see text). As reference points, vertical dashed lines indicate the end of the Second World War and the end of the Cold War.

Both models produce similar results, with the simulated cumulative production curves for each quantile group creating an envelope of variability within which the empirical pattern from 1823–2003 falls comfortably (Figure 7). That is, the observed variability in the production rates of wars of different sizes is plausible under a stationary process.

However, it is also clear that the period of 1913–1940 contained a relatively large number of very severe conflicts, even for a stationary process. This fact is illustrated by the movement over this period of the $x_{0.75}$ empirical curve from the lower to the upper part of its simulated ensemble. The subsequent lowered production rate of severe events over 60 years (the "Long Peace") moves the empirical curve back toward the middle of the null distribution.

1913-1940 contained a large number of severe conflicts. Such periods of extreme violence are genuinely unusual, while long periods of peace are relatively common. However, the joint likelihood of a period of long peace following a period of extreme violence is quite rare.

Using both models, we can estimate the likelihood of observing a simulated conflict time-series that contains either a similar period of extreme violence (28 or fewer years containing 11 or more severe events) or a similar long peace (63 or more years containing 5 or fewer severe events). And the joint likelihood of observing extreme violence followed by a long peace can be estimated. Under the second, semi-parametric model, such periods of extreme violence are genuinely unusual, occurring in only 7.6 ± 0.3% of simulations. In contrast, long periods of peace are relatively common, occurring in 57.7 ± 0.5% of the time. However, the joint likelihood of having a period of extreme violence that is followed by a period of long peace is quite rare, occurring only 0.57 ± −0.08% of the time. Meaning that under a stationary process, large conflicts do not tend to cluster together nearly as much they did during the 1913–1940 period. Seen in this light, the Long Peace is unusual because it immediately followed such an extremely violent period, which suggests that the underlying conflict-generating process may have undergone learning or adaptation.[38]

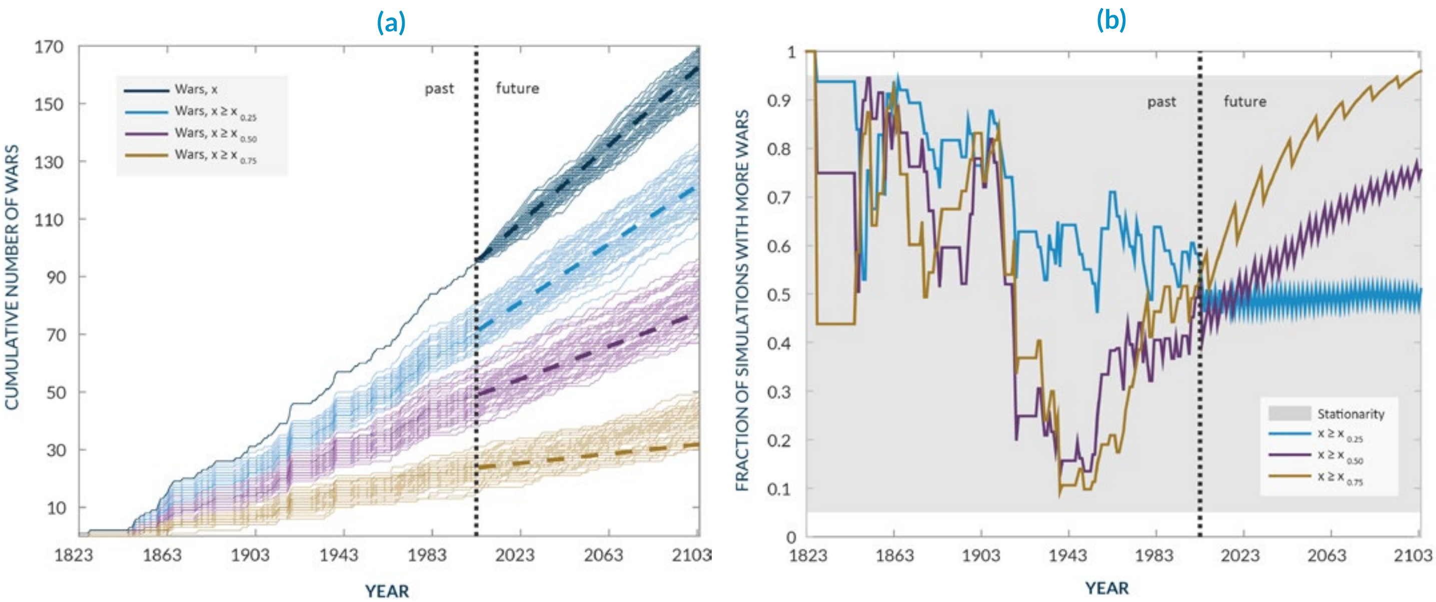
Peering into the Future

The general robustness of the stationarity hypothesis raises an important question: if the post-war pattern of having relatively fewer very severe conflicts continues, at what point in the future can we reliably conclude that the pattern is a trend and not a fluctuation? This question is formalized by calculating the point at which 95% of the simulated production curves under the stationary hypothesis have produced more conflicts than expected by extrapolating the post-war production rate into the future.

Villagers gather in war-torn Golo, Sudan. Photo by Ashraf Shazly/AFP/Getty Images

To simulate a conflict time-series that extends into the future, but still obeys a stationary process, we begin with the empirical war onset dates for the period 1823–2003. Then, for each of T additional years, a new war onset is generated following a Bernoulli process with parameter p, which is the inverse of the average delay of 1.49 years between new wars of any size in the post-war period. For each sequence of war onsets, war sizes are drawn using the same two approaches as above: we either sample with replacement from the empirical severities or draw severities semi-parametrically from the ensemble of power-law models. As before, having a large number of such simulated past and future time-series of conflicts produces a distribution of production curves that represent the variability expected under a stationary process.

Figure 8: Production Curves for Wars, Extrapolated into the Future



a) Comparison of the empirical production curves for different-sized wars, along with linear extrapolations over the next 100 years based on the post-war period, against an ensemble of production curves generated from a simple nonparametric model of stationarity. (b) The fraction of simulated production curves that contain more wars than observed in the past or extrapolated into the future, showing that the post-war moderation in the production of most-severe events becomes statistically unlikely only around 2100.

Finally, the production rate of the largest conflicts is extrapolated by extending a linear fit of the $x_{0.75}$ production curve from 1940–2003 for T more years. This extrapolated trend falls within the distribution of stationary curves for most of the next century, but eventually does cross into the lower tail around 2100 for the bootstrap model (Figure 8a) and around 2150 for the semi-parametric model.

This statement is quantified more precisely by calculating the fraction of simulated curves that have produced more conflicts by some year t than observed or expected (Figure 8b). This statistic provides a simple measure for how relatively unusual a particular production curve under a stationary model is, and a departure from stationarity would manifest as a fraction very close to either zero or one. Historically, the observed fractions for the $x_{0.25}$, $x_{0.50}$, and $x_{0.75}$ conflict groups fluctuate within the middle 90% of simulated trajectories, indicating that they are not statistically unusual. This pattern is consistent with past results showing the plausibility of the stationarity hypothesis. However, one also observes that the violent period of 1914–1940 corresponds to a large excursion in the production of relatively large events, although the maximum extent of this excursion is not dramatically unlikely under the stationary hypothesis.

In the extrapolated future, the post-war trend for the production of the largest events becomes progressively more unlikely as a statistical fluctuation over the next 100–150 years, depending on which model of stationarity for war sizes is used. In other words, we find that the Long Peace would need to hold for roughly another century to be statistically distinguishable from a large but nevertheless random fluctuation in an underlying stationary process for war sizes and onsets.

THE LONG VIEW

For a stationary conflict-generating process, both the production rate of new interstate conflicts and the distribution for the sizes of those wars is stable over very long periods of time. These features allow us, if we so choose, to make long-term statistical forecasts about war.

The 100-Year Forecast

Previously, this analysis estimated the marginal probability p_* that any particular war will be at least as large as the Second World War, which produced $x_* = 16{,}634{,}907$ battle deaths. This estimate is only reasonable under the stationary hypothesis, which the analyses here so far appear to support. Hence, assuming that both the historical production rate of interstate wars and the distribution of their sizes remain stationary over the next 100 years, our ensemble of models can be used to make a data-driven statistical forecast of the likelihood of observing at least one such large war.

The resulting ensemble forecast for a 100-year period produces at least one event at least x_* in size in 43.3% ± 0.2% of simulations, and the average number of such events which occurred over the forecast period is 0.62 ± 0.01. These forecasts illustrate that under the stationary hypothesis, the likelihood of a very large war is not particularly small over the next 100 years, even though the majority of simulated conflict sequences (56.7%) failed to produce a war at least as large as x_*. The accuracy of this forecast, however, depends on relatively strong assumptions, and if the underlying data-generating process were to shift fundamentally, this forecast would need to be modified.

One Billion Battle Deaths?

Under a stationary conflict-generating process, forecasts of any length can be calculated. The longer the forecast window, of course, the more precarious the assumption of stationarity may seem. Nevertheless, it is a useful exercise to consider very long periods of time, because such a forecast is equally as applicable to the past as to the future, since under a stationary process they are statistically exchangeable.

It is a useful exercise to consider very long periods of time, because such a forecast is equally as applicable to the past as to the future.

To make this point concrete, we can calculate the expected number of years that must pass before a conflict occurs with $x = 1{,}000{,}000{,}000$ (one billion) battle deaths. Such an enormous conflict would be globally catastrophic and would likely mark the end of civilization as we know it. Such a conflict is also not outside the realm of possibility, if current nuclear or foreseeable weapons were deployed widely.

Under the ensemble of models here, the median forecasted waiting time for such an event is 1,339 years. The underlying distribution, however, is enormously variable, with the 5–95% quantiles ranging from 383 years to 11,489 years. A median delay of 1,300 years does not seem like an especially long time to wait for an event this utterly catastrophic in size, and humans have been waging war on each other for substantially longer than that.

The implausibility of this prediction and the lack of evidence for such a conflict in the historical record of human conflict suggests that some aspects of the war size distribution are probably not stationary. Plausible candidates for non-stationary factors are easy to enumerate; e.g., world population, technology, political structures, etc., none of which are directly represented in war severity data.[39] Looking forward, however, stationarity may be more plausible,[40] in which case the prospect of a civilization-ending conflict occurring in the next 13 centuries is sobering.

DISCUSSION

The absence of a large war between major powers since the end of the Second World War is an undeniable international achievement. Whether this "Long Peace" should be expected to continue has been a mystery central to conflict research for several decades. Scholarship on the impacts that democracy,[41] peace-time alliances,[42] and economic development[43] have on the likelihood of wars presents a reasonable and evidence-based mechanistic argument that the post-war trend toward peace may endure. And these hypotheses are supported indirectly by broad evidence for a long trend toward less violence worldwide, per capita.[44]

However, these insights do not resolve the deeper question of whether the underlying dynamics of the geopolitical processes that generate interstate wars of different sizes have fundamentally changed since the end of the Second World War. If they have not, then the Long Peace may be a temporary pattern, driven by short-term factors, ephemeral processes, or simple luck, within a fundamentally more stable dynamical system. Answering this question is made rather more difficult because we exist within this system and contribute to its dynamics. Thus, the idea that we could control its direction seems reasonable, perhaps necessary. However, evidence from the study of numerous complex social and biological systems[45] suggests that this perspective likely underestimates the importance of complexity and overestimates our ability to understand complicated causes for complicated effects in a distributed, highly interconnected, and evolving system.

Photographic restoration by Adam Cuerden of public domain work of art, "The Thin Red Line."

By H. Piffard

The tension between claims of a genuine trend toward peace versus claims of a transient period within an overall stationary system can be viewed as a disagreement about dynamics at different scales, and a disagreement about null models. What we observe in the data can depend on the time scale we use to look for patterns or for exchangeability, and on how complicated we are willing to make the stationary hypothesis. A short-term trend toward peace can be entirely true, driven by identifiable and real processes, without being inconsistent with a process that is fundamentally stationary in the long run. That is, if the processes that drive peace are themselves non-stationary while the processes that drive war are stable, then observable trends toward war or toward peace will be entirely likely across a human lifetime.

Without a clearer understanding of the underlying mechanisms that drive the production of conflicts over long periods of time, or sufficiently broad and reliable data by which to identify them, we may never have a satisfying answer to the debate over trends in war. In the meantime, statistical analyses of the available data, like those conducted here, can provide some clues with which to constrain the debate and focus future work, in terms of both policy and research.

For instance, a stationary process for the generation of interstate wars of different absolute sizes is not inconsistent with an overall decline in per capita violence because the world's population has increased so dramatically over the past 200 years.[46] In fact, given the obvious and enormous non-stationarities in civilization over this time period, including population growth, a dramatic increase in the number of recognized nations, and technological advances in public health, communication, commerce, and war itself, it seems all the more remarkable that the threat of war in general has remained so evidently constant (Figure 7).

Within the context of interstate wars since 1823, little evidence is found for strong non-stationary patterns, including an overall trend toward peace or toward war, in either the sizes of wars, the durations of peace between war onsets, or their joint relationship—either over the full period of study or in the post-war period alone. Specifically, the distribution of war sizes after the Second World War is statistically very similar to the distribution before, and the size of the Second World War itself is not anomalous relative to the overall distribution of war sizes. The distribution of durations of peace before and after the Second World War are statistically very close, and the overall production rate of new wars of any size did not change substantially in the post-war period relative to the century of conflict that preceded it.

> *The stability of conflict production is remarkable, considering the dramatic growth in the number of states, increase in world's population, technological advances in public health, communication, commerce, and war itself.*

The stability of conflict production is a remarkable pattern, considering the dramatic growth in the number of states since 1823, a number that rose by nearly an order of magnitude. A data-generating process for interstate conflicts that depends in some way on the number of possible pairs of combatants would tend to produce more conflicts as the number of states increases. The stability of conflict production despite a growing international system appears to falsify this notion, and suggests that other factors mediate the production of new conflicts,[47] e.g., shared borders, shared democratic systems of governance, defensive alliances, etc.[48] However, the stability of conflict production remains puzzling in light of the historically complicated covariation of these factors across space and time.

Across the several analyses here, however, noteworthy circumstantial evidence of a trend toward peace was found, at least among the largest wars. Specifically, the relative frequency of the largest wars as a group ($x_{0.75} = x \geq 26{,}625$ battle deaths) did decline in the post-war period compared to any other size-group of wars in the same period or compared to wars of any size prior to the Second World War. That is, the Long Peace is not an imaginary pattern, even though compared to the tumult of war over the past 180 years, it is also not statistically implausible, given the highly variable nature and relative rarity of large wars to begin with. Overall production of wars, however, was stable, and so this decrease in the largest wars was balanced in the post-war period by a corresponding increase in the frequency of the smallest wars ($x < 2{,}167$ battle deaths). As a side effect of this shift away from large wars, the durations of peace between large wars was substantially longer in the post-war period than in the time leading up to the Second World War.

The period of 1914–1940 is particularly relevant to this discussion, as it includes many of the most severe conflicts (42% of conflicts $x \geq 26{,}625$, over only 15% of the total time period). The appearance of so many large events in such a short period of time would be an unusual pattern under a stationary process, and this burst of events was very nearly enough evidence to violate the stationarity hypothesis in the direction of escalating war. The "Long Peace" pattern that immediately followed it, in which the production of large events returned to a rate close to that of the 1823–1913 period, would also be an unusual pattern under a stationary process. The co-occurrence of these two unusual bursts, one of many large wars and one of very few of them, would be even more unusual under a strictly stationary model with strong assumptions of independence between consequence events, and thus may be evidence of an underlying non-stationary process, e.g., learning or adaptation in the international system.[49]

However, the idea of the Long Peace is not predicated on a long run of good luck, and is instead based on the reasonable notion that wars are not independent of each other.[50] It is thus somewhat coincidental that the Long Peace has served mainly to balance the statistical books since 1823 in terms of the overall production of large wars. From this perspective, only if the post-World War II trend of peace were to continue for another 100 to 150 years could we reliably conclude, on the basis of statistical patterns alone, that the trend was not simply a lucky but long fluctuation in an inherently highly variable stationary process (Figure 8). There is also the complicating factor, unaddressed here, that interstate wars are only one conflict variable among many,[51] and these variables cannot be considered wholly independent. Hence, the lack of a trend in interstate wars may occur because there is a compensatory trend in another variable, or vice versa. Untangling the interactions of these variables, and characterizing their trends, is a valuable line of future work.

These facts and figures serve to illustrate the fundamental importance of work to prevent peace-promoting institutions or systems from falling in the face of stable or contingent processes that drive the production of war.

If the stationary hypothesis is correct, however, over this same period of time the risk of another war with tens of millions of battle deaths is shockingly high (to say nothing of the longer-run likelihood of a civilization-ending conflict). These facts and insights serve to illustrate the fundamental importance of concerted and serious work to ensure that the Long Peace endures and to prevent fragile peace-promoting institutions or systems from falling in the face of stable or contingent processes that drive the production of war. Much of this work must be done on the policy side. In the long run, however, research will play a crucial role by developing and evaluating mechanistic explanations, at multiple scales, of the likelihood of war,[52] which will help shed new light on what policies—at what scales—will promote peace.

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