Eastern Front Data and Simulation Methods

Soviet Union Data

Soviet Losses

The Krivosheev data

The total Soviet deaths per quarter are based on the official Krivosheev data (Кривошеев, 2010), but with significant adjustments. Krivosheev reports the total number of deaths, including POW deaths, of 8,601,000. As many other commentators have argued, this is far too low. This can be brought out by considering the final status of all mobilised soldiers at the end of the War. Krivosheev reports the following:

Row	Final status at end of war (June 1945)	Krivosheev reported	Krivosheev fixed
A	In armed forces (army, navy, and civilians)	12,840,000	12,840,000
B	Discharged during war	9,684,100	8,386,500
C	Dead from all causes in military units	6,885,100	6,885,100
D	Dead reservists not yet reached units	500,000	500,000
E	Dead POWs and MIA	1,783,300	1,783,300
F	Returned POWs	1,836,000	1,836,000
G	Found MIA later reconscripted	939,700	0
H	Total by final status	34,468,200	32,230,900
I	Total unique mobilised	34,401,765	34,401,765
J	Difference from reported unique mobilised	66,435	-2,170,865

The problem with these figures is that rows B and G do not represent final statuses. 'Discharged during war' is something that occurred to a soldier during the war, not a final end state. This is explicitly identified as a problem by (Lopukhovsky & Kavalerchik, 2017, p. 109). Furthermore, Krivosheev elsewhere reports the number discharged who were later reconscripted as 1,297,600 (see page 37, 1,154.8k+142.8k). This final state should then be adjusted to refer to 'discharged during war and not reconscripted or dead at war's end', equal to 8,386,500 (9,684,100 less 1,297,600). Furthermore, the MIA who were found and then reconscripted is also not a final state. All these individuals will appear elsewhere in the data, depending on whether they were later discharged, were killed, or survived the war remaining in the army. When these errors are fixed, we find that Krivosheev is unable to account for a full 2.2 million mobilised soldiers. This is clear evidence that his estimate of the non-POW deaths (6,885,100) is far too low.

On the plausibility of undercounting recruits, (Lopukhovsky, et al., 2017, p. 139):

> "It is not at all by chance that Krivosheev made the reservation 'demographic casualties of roster strength servicemen' in the corresponding place. Those who were mobilized but who were not included in the unit lists for various reasons (including because of an irresponsible attitude toward personnel records) were simply listed among the losses of the USSR civilian population ... the Red

> Army's identification system performed rather poorly. A soldier's identification tag consisted of a small plastic capsule, closed by a screw cap, containing a paper insert. This insert was to be filled in by its owner with basic data about himself and his family. However, this information did not always survive. A capsule could be easily destroyed by fire or penetrated by groundwater, thereby ruining the fragile insert inside or washing out its text. In addition, many soldiers did not even fill in their inserts. Many underestimated their importance, and others considered filling them in a bad omen and refused to do so because of superstition. Furthermore, not all soldiers had identification tags – they were adopted by the Red Army shortly before the war, on 15 March 1941, and were abolished on 17 November 1942 without any equivalent replacement. For all of these reasons, it is understandable why millions of missing Soviet servicemen have remained unidentified. The metal dog tags used in the Wehrmacht were much more effective in identifying those killed in action."

Problems with official data are also noted in (Frieser, 2017, p. 154)

> "In reality, however, the Red Army must have incurred considerably higher personnel losses. As one Russian historian has convincingly demonstrated, the official loss statistics are full of gaps and inherent discrepancies."

Also from the same source, page 203:

> "Unlike the Wehrmacht, which set great store by good training and sought to integrate new soldiers in a 'tight-knit community', the Red Army treated its human resources at times like mass-consumption material. In the second half of the war the male population of the liberated areas was frequently dispatched to the front without any training worth mentioning. Tractor drivers straight from work on collective farms suddenly found themselves deployed as tank drivers or even tank commanders."

Also (Sokolov, 2013, p. 74):

> "The official mobilization figure in the USSR, in addition to the fact that military committees probably miscalculated the number of conscripts, also does not include members of volunteer corps, whose formation was a matter for Party and not the military organs… In addition, the official figure does not include those who were conscripted directly into units, whose number is difficult to estimate. It was undoubtedly great, numbering in the millions. These conscripts were minimally trained, and even at the end of 1943 were often thrown into battle without uniforms, in civilian clothes, and suffered heavy casualties."

In When Titan's Clashed, David Glantz reports:

> "During the winter-spring campaigns of 1944, the two Ukrainian fronts had become seriously depleted and had made up their losses by sweeping all available manpower from the liberated regions of the Ukraine and Bessarabia. Men were pulled out of villages, haystacks, or wherever they could be found, put into uniform, issued weapons, and incorporated into rifle divisions. One rifle division of 5th Shock Army grew from 3,800 to 7,000 men in this manner, but these new recruits were only marginally effective."

A further problem with Krivosheev's data is that the number of POWs is clearly a gross underestimate. Krivosheev reports 4,454,709 POWs and missing (see page 51), which is already significantly more than the 3,619,300 sum of the E and F rows in his 'final status' data (see page 41). By contrast, the German

data reports 5,814,000 Soviet POWs, of which 3,039,200 survived the war. This figure differs from the 1,836,000 returned POWs reported by Krivosheev because it ignores the 1,023,000 POWs released by Germany during the war, and 180,000 POWs who emigrated rather than returning to the USSR. It should be noted that some of the 1,023,000 POWs released during the war would have died, since most of these were either released because they were too injured or sick to work for the Germans, or to serve as Hilfswillige in the Wehrmacht, or in other auxiliary police and occupation units. Accurate data for casualty rates of Hiwi are lacking. Based on Krivosheev's figure of 200,000, as well as a similar figure of 140,565 dead and missing up to 31/1/45 by OKW, though bearing in mind that not all of these would have been ex-POWs, a rough figure of 30% was used for the number of these released POWs who subsequently died. This figure however could easily be much higher. On the undercount of POWs, the (Lopukhovsky, et al., 2017, p. 83):

> "This disproportion arose as a result of the fact that the authors calculated casualties only according to troop reports without paying attention to their reliability. They took into account only what had been reported. Since reports were not sent from encirclement, it meant that there were no casualties."

Also on page 101:

> "The main difficulty in computing military-operational losses, including irrecoverable ones, in these operations is that information from formations and armies that had become encircled or had withdrawn to a great depth sometimes failed to reach front headquarters and the General Staff. Poorly organized personnel records in units and formations, along with irregular, unreliable (sometimes simply false) reports from lower headquarters, made the computation of casualties difficult."

Yet another limitation with Krivosheev's data is that he does not include deaths from NKVD and border troops, which by Mikhalev is equal to 159,000.

There are further major problems with Krivosheev's numbers. In the table below Krivosheev presents a breakdown of all soldiers discharged during the war.

Row	**Discharged during the war as per Krivosheev, page 41, 37**	
A	Injuries and illness	3,798,200
B	Transfered to industry, local air defence, paramilitary guards	3,614,600
C	Transfered to NKVD and special units of other departments	1,174,600
D	Transferred to foreign armies (Poland, Romania, Czech)	250,400
E	Deserters	212,400
F	Suspected of treason, sabotage	206,000
G	Punishment battalions	427,900
H	In detention (included in active armed forces so excl from Krivosheev total)	436,600
I	Total	10,120,700
J	Of which probably dead by war's end (my estimates)	777,978
K	Of which later reconscripted (from discharged wounded, sick, or on leave)	1,297,600
L	Net discharged during war and survived	8,059,106
M	of which estimated wounded	4,527,161
N	of which estimated non-wounded	3,531,945

Of most relevance in these figures is that rows F, G, and H likely include large numbers who were killed before the end of the war. In particular, I assume that all those suspected of treason and sabotage were executed, and 69% of those in detention died (Statiev, 2010). The casualty rate of those in punishment battalions (shtrafbat) is highly uncertain, but based on rough estimates of twice the standard casualty rates, an estimate of 60% was used. Adding these yields a total of 763,994 additional deaths not recorded elsewhere by Krivosheev. Subtracting this from the number discharged during the war yields a new total of 7,622,506.

Correcting Krivosheev's data

Making all the aforementioned adjustments to Krivosheev's reported death totals yields the results shown in the table below.

All deaths by source	Krivosheev reported	Krivosheev fixed
KIA and died from wounds	6,885,100	6,885,100
Dead reservists		500,000
Dead POWs	1,783,300	2,840,800
Released POWs subsequently died		347,888
Dead from prison, penal battalions, execution		763,994
Dead NKVD & Border Troops		159,000
Other unaccounted losses		
Total deaths	8,668,400	11,496,782
Non-POW deaths	6,885,100	8,655,982

Even after these corrections, it is unclear whether all Soviet casualties have been accounted for. Indeed, there is strong reason to believe that this still represents an under-estimate. It is important to note what is excluded from these figures (Ellman & Maksudov, 1994):

> "It is important to note that this figure of 8.7 million only includes the regular armed forces and the frontier troops and internal troops of the NKVD. It does not include non-conscripted fighters (partisans, resistance fighters and the underground in territories occupied by the Germans). Nor does it include railwaymen fighting in their own militarised detachments, local anti-aircraft defence, the militarised fire service, police in frontier areas who fought against the invaders etc."

In this study, I use a total figure for all Soviet military deaths during WWII, including dead, missing, POW deaths, executions, and deaths in imprisonment, for all branches of the Soviet military, of 13 million. This figure is based on three separate lines of evidence.

1. Taking the total of counted losses (8,668,400 army+500,000 reservists + 159,000 NKVD) is 9,327,400. A comparison of the German OKW figures with the Overmans data (Overmans, 2009) indicates that through to the end of 1944, official data underestimated German deaths by about 34% (5.6 million POW and dead according to Overmans compared to 3.7 million from OKW. Assuming that roughly similar limitations and problems faced the Soviet military, applying the same percentage increase to the Soviet data results in a figure of 14 million.
2. From The Great Patriotic War Anniversary Statistical Compilation (Суринов & Оксенойт, 2015, p. 24), the population deficit of working age women as a result of the war is given as 3.9 million, compared to 17.1 for men. The difference is 13.2 million, most of which is likely attributable to military losses.

3. From the TsAMO data (Lopukhovsky, et al., 2017, p. 161) we get a total of 17.2 million losses recorded. Less returned POWs and emigres, and less MIAs found on reoccupied territory, this comes to 13.4 million. Another more recent reference to the same data from (Ismailov, 2011) cites 13,850,000 'irreversible losses'.

On this data from this source:

> "Thus, complete information, including information from rear military districts about servicemen who died from wounds, illnesses, or other reasons in hospitals, was concentrated in this collection (of the TsAMO). In addition, immediately after the war and until 1949, military commissars made so-called 'house rounds' [dvorovoi obkhod], that is, they made the rounds of homes with personal inquiries of relatives of those front fighters who did not return from the war for the purpose of exposing persons missing in action. Servicemen recorded in this way comprised 60 percent of the card index of losses."

Soviet Wounded

With the total number of deaths now available, it is still necessary to produce a monthly series of deaths for the Soviet army. Total figures for the Soviet army at the start of each month are taken from Krivosheev (39-40), rounded to the nearest thousand. The number in hospital is from the same source. As hospital numbers are given to the end of the year, the rate at which patients are released can be estimated by averaging the rate at which the number hospitalised falls from Jun to Dec, following the end of fighting in Europe. The small number of casualties from the invasion of Manchuria is ignored as being insignificant for the purpose here. This gives rise to a monthly hospital release rate of 0.215 per month. This data is then used to estimate the number of newly wounded each month, as the difference in number in hospital from one month to the next, plus the estimated number released during that month.

The estimated number of wounded demobilised is taken as 1/3 of the total number of wounded, which is the same ratio used for Germany (see below). Krivosheev reports 3,798,200 demobilised during the war for sickness and wounds, though this is likely to be an underestimate, as some wounded in action would be transferred to industry or elsewhere. Hence the slightly higher figure of 4.5 million obtained using the German ratio seems appropriate.

Monthly casualty series

The number of newly wounded each month is then used in combination with the quarterly losses from Krivosheev to provide estimates for the monthly number of deaths (excluding POW deaths). The number of deaths each month was calculated as the proportion of the quarterly wounded in that given month, times the total number of deaths in that quarter. In other words, the total quarterly deaths are apportioned in accordance with the relative number of wounded in that month. These estimates were corroborated in two ways. First, the total number of patients estimated to be released from hospital over the course of the war, plus those still in hospital by the end of 1945, total 10,412,000. This compares to the total estimated new wounded over the course of the war of 10,610,000, a difference of only about 1.9%, indicating that the estimated number of new wounded is close to the correct amount on average. Second, the estimated number of quarterly wounded is compared to the total number of quarterly deaths. Excluding Q3 of 1941, when the number of wounded taken to hospital would have been far lower due to the enormous number of POWs taken in this time, the R^2 for the correlation of quarterly deaths and quarterly new wounded is 0.599, indicating a strong relationship between these variables, as would be expected if the new wounded series is accurately tracking battlefield events.

Soviet POWs

The data for Soviet POWs was obtained from German records, since as discussed above Soviet records are known to underestimate POWs. The main source was the monthly summaries produced for the OKW and the Quartermaster general. The BA-MA files drawn on are RW19/1387-1394, and RW6/542 and 544-547 (see http://www.dupuyinstitute.org/ubb/Forum5/HTML/000098.html**).** Missing data from this source was filled in as follows:

- The incomplete data for Feb 1942 were filled using the total for January to March 1942 of 104,128 according to the OKW report of 4.4.42 (see: Die Berichte des Oberkommandos der Wehrmacht, 1. Januar 1942 - 31. Dezember 1942, Leipzig 1943, p. 94).
- The missing data for Jul 1942 was filled using the total for July-August 1942 of 625,000 from (Boog et al., 2001, p. 1054).
- The missing data for October and December 1943 were estimated by distributing half of the missing quarterly total to each month.
- From July 1944 onwards German data are unavailable so estimates have been made based on Krivosheev's quarterly figures. However Krivosheev's data includes both POWs and MIA, so need to be adjusted downwards to account for some MIAs not captured. This was done by comparing the German and Krivosheev data for 1943 and the first half of 1944, and finding that the German data consistently averages around 70% of the Krivosheev data. Thus the missing German quarterly data was estimated as 70% of the Krivosheev data, and distributed equally to each month in the relevant quarter.
- It was assumed no Soviet prisoners were captured in May 1945.

Soviet Strengths

The monthly series of Soviet front strength was derived from the quarterly series given in Krivosheev, page 69. The missing months were interpolated using the monthly army totals give in Krivosheev, page 39-40, multiplied by the ratio of the total Soviet front strength to the total army size. These ratios, in turn, can be calculated directly using the quarterly data, and then are interpolated linearly for the missing months in between the quarterly data. The exception are the monthly front figures between Jun and Oct, which were directly interpolated linearly using the front figures (i.e. not using army totals or the ratio), since the army was expanding rapidly during these months and hence the ratio changed too rapidly to reliably use for interpolation. Soviet front strengths for these months in particular should be regarded with significant caution, since the situation was changing so rapidly it is unlikely accurate records were kept about the total number of Soviet soldiers at the front. Note that the number includes all regular military personal at the front, regardless of whether they are immediately fit for duty, and including non-combat troops. Irregular and paramilitary forces, and wounded sent to rear hospitals, are not included.

Soviet Reserves

A reconstruction of the full population of working age men as at Jun 1941 over the course of the war is shown in the table below.

Soviet Union Personnel	Jun-41	Jan-42	Jan-43	Jan-44	Jan-45	Jun-45
Working age men	52,300,000					
Available and in military	30,050,000	31,175,000	32,355,000	33,555,000	34,735,000	34,735,000
(Including newly of age)	-	1,125,000	2,305,000	3,505,000	4,685,000	4,685,000
Less active army	4,276,000	9,098,000	10,967,000	11,917,000	11,999,000	11,827,000
Less active navy	352,000	486,000	428,000	460,000	528,000	507,000
Less civilians in military	199,000	306,000	370,000	459,000	512,000	507,000
Less cumulative KIA & POW	-	5,619,000	9,838,000	12,706,000	14,956,000	15,973,000
Less cumulative wounded	-	357,000	1,430,000	2,773,000	3,901,000	4,527,000
Less cumulative discharged	-	345,000	1,036,000	1,727,000	2,418,000	3,397,000
Total cumulative conscripted	4,827,000	16,212,000	24,069,000	30,042,000	34,314,000	36,737,000
Total potential reserves	25,223,000	14,963,000	8,286,000	3,513,000	421,000	-2,002,000
Plus liberated POWs	-	-	-	-	-	2,528,000
Less WIA reconscripted	-	1,297,600	-	-	-	-
Less on occupied territory	-	5,471,000	6,035,000	3,281,000	40,000	-
Total available reserves	25,223,000	8,194,172	2,251,448	232,140	381,000	523,000

The number of military-aged men as of 1941 is taken from (Суринов, et al., 2015, p. 24). Note that this refers to the 1941 borders, including recent annexations. The total number available for military service is from a Russian report 'Report on Mobilization Resources and their Use during the War (1 September 1942)', as published in The Price of Victory (Lopukhovsky, et al., 2017), Appendix C. The total personnel available or already utilised by Sept 1942 is given as 31,500,000. Subtracting the conscripts born in 1924 and 1925 (given as 1,450,000), the total available in mid-1941 was calculated as 30,050,000. The additional conscripts 'newly of age' for subsequent years are taken from Krivosheev page 37. Active army totals (including in hospital) are from Krivosheev pages 39-40, while navy and civilians in military from Krivosheev page 38 (Jun 1945 figures are estimates based on Jan figures). KIA, POW, wounded, and discharged numbers are derived from my own estimates, as described in previous sections. The sum of all indented rows gives the total cumulative conscripted. To determine the number of reserves actually available at each given time, the total potential reserves is found by simply subtracting total active military and cumulative losses from total available manpower. From this 'potential reserves' figure must be added any liberated POWs (assumed to only become available by June 1945), wounded soldiers later reconscripted (assumed to have occurred in 1942), and manpower on territory occupied by the Germans. The method by which the manpower on occupied territory was estimated is explained in a subsequent section.

It is interesting to note that the implied total number conscripted from these data (36.7 million) is very close to the total conscripted figure reported by Krivosheev on pages 37-41 (36.6 million). While Krivosheev states that 2.2 million men were conscripted twice and so only 34.4 million unique men served, my reconciliation indicates that either there was an undercount of around 2 million men conscripted, or the 2.2 million conscripted twice is actually a fudge factor introduced into the data by Krivosheev in order to get his figures to add up. This is supported by the inconsistent use by Krivosheev of the 939,700 MIA later found and 1,297,600 discharged and later reconscripted (these add to about 2.2 million). Note that Krivosheev reports 36.6 million total mobilised during the war. But adding up all the categories by final status at the end of the war, he only finds a total of 32.2 million, leaving a discrepancy of 4.4 million. It is my view that this discrepancy represents mostly unrecorded deaths and POWs.

However to avoid dealing with this problem in his data, he arbitrarily adds the aforementioned 2.2 million to the 'final status' figures even though 'MIA later found' and 'discharged later reconscripted' are not final statuses and so should not be separately added. This brings his final status figure up to 34.4 million. Then he declares that the 2.2 million have been 'conscripted twice', and therefore deducts them from the 36.6 million total mobilised figure, even though it is never explained why soldiers who were MIA or discharged to industry and later remobilised should be double counted in the data in this way. I believe that there is no basis for his assertion that these 2.2 million are actually double counted in the 36.6 figure, and instead he subtracts them in order to arrive at a 34.4 figure to match that he obtained from the final status data. I believe that my reconciliation shows that Krivosheev's figures are highly implausible.

I estimate that about 3.5 million non-wounded soldiers were discharged during the war, however this does include those discharged to NKVD, anti-aircraft defence, and other paramilitary roles, which are comparable to tasks performed by members of the German Wehrmachtsgefolge, which in German data is counted as part of the armed forces. Hence for the simulation I will only count the discharges from Apr 1942 onwards, for a total of 1.5 mil discharged during the war from any armed forces occupation. This is on the lower side of my estimate of perhaps 2 million discharged in this way.

Minor Allied

Romania

Strength figures are taken from Wikipedia. The main Romanian source I use (Axworthy et al., 1995, p. 214) reports 170,000 losses fighting with the Soviets, but this includes wounded. At a crude estimate, about half of those would have been permanent losses.

Poland

A Soviet-controlled Polish division was formed May 1943, formed into Corps in March 1944, and then into 1st Army in July 1944. The 2nd Army was formed in Aug 1944, but personal shortages meant that it wasn't operational until Jan 1945. Estimates are made based on the formation size, assuming standard Soviet division strength of around 10,000. I was unable to find any data for Polish losses fighting with Soviets, so I guessed about half the Romanian figure (80,000) based on force levels. The monthly loss series was estimated based on the product of Polish force levels and Soviet losses for that month.

Bulgaria

The Bulgarian figure is taken from Wikipedia. Losses are likewise taken via Wikipedia from Erlikman 2004.

Germany Data

German Losses

The Overmans data

German data are complicated by numerous factors that are not relevant when considering the Soviet data. These complications include:

1. All figures of strengths and losses must be distinguished as either describing to the overall German war effort, or the Eastern front only.
2. A significant number of German recruits were from territories outside of Germany's 1937 borders, and therefore are often excluded from certain data sources.
3. Especially near the end of the war, a significant fraction of the German military's total strength was outside the organisation of the Wehrmacht, in particular in the Waffen-SS. Figures must be checked to determine whether they refer to all German forces or only the Wehrmacht.
4. Large numbers of foreigners served in both the Wehrmacht and in the Waffen-SS. These non-ethnic Germans are often excluded in figures for recruit and loss numbers.

German loss data are based on the results of the statistical survey of personnel files completed by German historian Rüdiger Overmans and published in *Deutsche Militarische Verluste in Zweiten Weltkreig* (Overmans, 2009). The monthly total deaths series is taken directly from Overmans. The Ostfront death series is also taken from Overmans, with the 1945 figures (which Overmans does not give owing to lack of data) estimated as two-thirds of the total deaths, in accordance with Overmans' rough estimate. These data, however, also include POW deaths. Therefore, estimates for the total number of POWs and total POW deaths are needed. It should be noted that the Overmans data are significantly higher than the official OKW loss data (Mueller-Hillebrand, 1969, p. 266). This is likely due to inclusion of about 250,000 deaths from paramilitary organisations not included in OKW data, plus several hundred thousand deaths from wounds, plus Overmans believes that the OKW system for centrally recording losses progressively broke down during the retreats of 1944, leading to an underreporting of casualties.

Foreign recruits

Confusingly, recruitment data for the Wehrmacht and Waffen-SS include foreigners serving in the SS, while Overmans' casualty data include ethnic Germans only, hence there is a need to adjust the Overmans data for foreigners serving in the SS. I estimate this based on 500k of 900k in Waffen-SS being foreigners, from (Stein, 1984, p. 138). Foreigners were first recruited into the SS from Apr 1940.

Foreigners or 'Hiwis' serving with the Wehrmacht appear not to be included in any statistics, except for overall Eastern Front strength. Therefore estimates have been made utilising Hiwi yearly totals (Mueller-Hillebrand, 1969, p. 251), with monthly series interpolated using the annual data. However the April 1945 value of 71k seems implausibly low, so has been ignored. Instead, values from Jully 1944 onwards interpolated on the basis of estimated recruits less losses. The total number of foreigners serving with the Wehrmacht was estimated at 600,000, based on (Abbott, 1982, pp. 3-4), calculated as 30+3+2 =35 divisions times 15,000 each + 50,000 Italians = 600,000 total. Adding this to the Waffen-SS yields a grand total of 1.1 million foreigners in German service over the course of the war. This is equal to 6% of the number of ethnic Germans who served in the Wehrmacht or Waffen-SS over the course of the war. In both the Wehrmacht and SS, foreigner casualty rates are assumed to follow the trends of the German monthly series, adjusted in accordance with the proportion of foreigners serving.

German wounded

No reliable data are available for German wounded, so the wounded series was estimated using a factor of 1.33 times the Overmans deaths series. This factor of 1.33 is taken from the Soviet wounded to deaths ratio. An alternative German wounded series was constructed based on the total casualty data from with Rüdiger Overmans' paper 'Menschenverluste der Wehrmacht an der Ostfront' (link here)', using OKW data from Jun 1941 to Dec 1944. This series has a 0.768 correlation with the Overmans wounded series over the same period, thereby providing some validation for this method. However owing to being more complete over the entire war and being directly comparable to the Overmans deaths data, the imputed Overmans series has been used instead of the OKW estimates. Note that (Sorge, 1986, p. 63) gives a total wounded for all Wehrmacht up to end of Jan 45 of 4.429 million, which is close to the estimate given here (5.3 mil to the end of Jan 45).

To estimate total wounded permanently disabled (discharged from the armed services), data from (Askey, 2018, p. 177) was used, according to which 66% of wounded remained in Wehrmacht/Waffen-SS, and 56% could return to front line duty. Compare with Overmans' paper, which reports 62% of all losses in the East as wounded, 'around half' of which returned to service. On the basis of these data, the figure of 1/3 of all wounded being demobilised was used.

German POWs

No single monthly series for German POWs is available, so one had to be constructed from a combination of different sources. Since only permanent losses are relevant, the small number of German prisoners captured during the Polish and French campaigns who were soon released can be ignored. Thus, the only German prisoners of 1940 were aircrew captured during the Battle of Britain, for which I found estimates online of about 1000 (no good source here but the number is so small as to not much matter). The monthly series of prisoners captured by the Western Allies (predominantly in North Africa) during 1941 and 1942 are taken from the quarterly data given in (Overmans & Goeken-Haidl, 2000, p. 272), and are allocated by month in proportion to the non-Eastern Front deaths recorded in that month. Since these numbers are generally lower than one thousand, a great deal of precision in such estimates is unnecessary. Western POWs for Jan-May 1943 are based on a figure of 130,000 Germans captured in total in 1943 (Marshall, 1996, p. 253), with the monthly estimates prior to the main surrender in May taken from the Overmans POW figure for Q1 1943 and allocated by month in proportion to the non-Eastern Front deaths recorded in that month. Western prisoners in July/Aug 1943 were mostly taken in Sicily, and so are based on a figure of 10,000 total German prisoners captured during that campaign given by (Ufficio storico dello Stato Maggiore dell'Esercito (USSME), 1993, pp. 440-441). These data are divided between July/Aug in proportion to the Overmans deaths from these two months. Western prisoners from Sept 1943 to May 1944 are largely from Italy, and have been estimated using the Overmans POW quarterly data from this period. Monthly prisoners taken in North-Western Europe are given by Wikipedia (see here) from (SHAEF, 1945). The total number of German POWs from the entire Italian campaign in (Marshall, 1996, p. 202) is given as 357,000, however these values seem unreasonably low given that the German strength is given as 440,000 as of early April (Frieser, 2017, p. 1158). As such I have assumed that 400,000 Germans were captured by the end of May (some deaths and a few escaped to Germany presumably). I have allocated this 400,000 to April/May in proportion to the ratio from North-Western Europe, since no additional data is available for this period in Italy. The months of July 1944 to March 1945 were largely static in Italy, so an arbitrarily small value of 1000 was assumed, as no other data are available.

German Strengths

Total numbers in all German military branches up to July 1942 are taken from (Kroener et al., 2000, p. 1103). Thereafter monthly figures are not available, and so a monthly series between August 1942 and June 1944 was interpolated using annual values from (Mueller-Hillebrand, 1969, p. 251), along with a figure for Oct 1943 from (Kroener et al., 2003, p. 1039). Note that there are some small discrepancies between the two sources in 1940, but I have gone with the more complete GSWW values, interpolated between annual data. Since the Wehrmacht did not change dramatically in size from late 1942 to mid-1944, I do not believe this should be a great source of error. For months after June 1944, values are estimated based on adding estimated intake less all forms of losses. Das deutsche Heer gives a figure of 7,830,000 for end of April 1945, which seems far too high based on my numbers. It may represent paper strength rather than actual strength.

Eastern front strengths up to July 1944 are from (Kroener, et al., 2003, p. 1020). Data for August to October 1944 are from (Frieser, 2017, p. 1170). Data for Jan 1945 are from (Dear & Foot, 1995, p. 1235). The final May 1945 figure is based on Bundesarchiv-Militärarchiv (BA-MA) document RH 2/1341 (under OKH RH 2 General Staff of the Army), as presented on https://forum.axishistory.com/viewtopic.php?t=88842. Missing months are interpolated by averaging. See also the final appendix of When Titans Clashed for a comparable set of numbers. Glantz gives slightly higher numbers for November 1944 to April 1945, though it is unclear what the source for this is, and I regard these are less plausible than a gradual reduction of German strength until the end of the war.

German Reserves

Total intake into the Wehrmacht excluding the Waffen-SS by year is taken from (Overmans, 2009, p. 222), for a total of 17.3 million. Waffen-SS recruits are estimated by taking SS losses (from the same source) and adding these to the growth of the Waffen-SS strength as given by Waffen-SS size at end of year, (Kroener, et al., 2003, p. 1062). These data only include ethnic Germans. Foreigner recruits into the Waffen-SS are added in proportion to the growth of the SS in a 5/9 proportion (as 500,000 out of the 900,000 who served are estimated to be foreigners, as discussed above). Foreign recruits into the Wehrmacht are estimated using annual data from (Mueller-Hillebrand, 1969, p. 251), interpolated between annual data. However, the provided value for Apr 1945 value of 71,000 seems implausibly low, so has been ignored. Instead, recruits from Jul 1944 onwards are interpolated on the basis of 600,000 total recruits less losses.

Total number in the German Armed forces, including civilians and foreigners annually up to Jun 1944 are taken from (Mueller-Hillebrand, 1969, p. 251). A monthly series is then interpolated between annual data. For the remainder of the war, the total armed forces size is estimated based on adding estimated intake less all forms of losses. Note that Das deutsche Heer gives a figure of 7,830,000 for the end of Apr 1945, which seems far too high based on my numbers. It may represent paper strength rather than actual strength. I estimate the actual value to be closer to 5 million. From July 1944 to the end of the war, I estimate that about 2 million men were taken from the Wehrmachtsgefolge and moved to the Wehrmacht combat forces. This reconciles a discrepancy that otherwise develops between the number of recruits inducted into the Wehrmacht services, the number of permanent losses, and the remaining strength size. Essentially, it seems that in the last 10 months of the war, the Wehrmacht force numbers were maintained as high as they were by cannibalising the noncombat and reserve forces.

Additionally, (Mueller-Hillebrand, 1969, p. 253) reports about 2 million non-wounded discharged from the Wehrmacht during the war, though I believe most of these were between the fall of France and the invasion of Russia, as otherwise I find it impossible to reconcile personnel numbers for this period. This is

consistent with the demobilisation of at least 200,000 WWI veterans during this period (Kroener, et al., 2000, pp. 947, 964). There was a total of 1.2 million WWI veterans in the Wehrmacht in September 1939, and it is likely that the majority of these were discharged before Barbarossa (Kroener, et al., 2000, p. 836). Also during this time, hundreds of thousands more skilled workers were released to industry (Kroener, et al., 2000, p. 968). My estimates for the number of non-wounded discharges based on the difference between losses, new recruits, and force strengths are about 2.7 million, but I use the 2 million figure as per the figure given in (Mueller-Hillebrand, 1969, p. 253).

My estimated series of German reserves, calculated by extrapolating reserves available at the start of the war less losses and plus new recruits, is shown in the figure below. Note that this incorporates a change in the number of Germans available for service (due to changes in age requirements and exclusions) in Sept 1943, as reported in (Kroener, et al., 2003, p. 1025). The total reserves available to the Germans based on my estimates are shown in the figure below.

Minor Axis

Italy

The 60,000 strong Italian Expeditionary Force fought in Russia in 1941 (Germany's Eastern Front Allies, p. 28). About 80,000 of the 230,000 peak strength was lost in Stalingrad and aftermath according to Oxford Companion to WWII p. 468; the remainder were withdrawn to Italy around March/April 1943. Monthly Eastern Front losses from (Istituto Centrale di Statistica, 1957), but adjusted upwards to total 90,000 instead of 73,000, in line with the more recent source (Multari, p. 4).

Romania

The major source for Romanian data is (Axworthy, et al., 1995). Page 45 gives gives a total of 326,000 Romanian troops involved in Barbarossa. The strength from October 41-March 42 is taken from Appendix Table C of 'When Titans Clashed'. (Axworthy, et al., 1995, p. 114) gives a strength of 230,000 at Stalingrad in November 1942 (the 3rd and 4th armies), which fell to around 90,000 by around February 1943. The situation was pretty messy during January, so I set 90,000 as the February figure. I think this also matches German data better, where deaths are often registered in the following month because of those reported missing. The same source (pages 127 and 131) gives April and October 1943 figures for forces east of the River Bug, which I use to interpolate between. For 1944 data, (Dear, et al., 1995, p. 747) gives 20 divisions on Eastern front as of August 1944, which assuming 10-15k average is 250,000 men. Other sources give much higher figures of around 450,000, however this includes home army troops stationed in Romania, which I doubt had much fighting strength or contributed much to fighting the Soviets. Total losses by

period are taken from (Axworthy, et al., 1995, p. 216). Period losses are converted to a monthly series by weighting by the product of the Romanian strength in a month and the German losses in that month (i.e. losses assumed at the German rate per total manpower).

Hungary

Unfortunately the quality of Hungarian sources is much lower than for Italy and Romania, so I had to construct estimates from piecemeal data. In 1941 the Hungarian Carpathian Group fought with the Germans in Russia. I estimate the strength of this formation using division numbers taken from (Ellis, 1993, p. 178), and convert to troop strength by comparison to the 200,000 peak at Stalingrad. The Hungarian Second Army was deployed to the East between May and July 1942 (Abbott, 1982, p. 15). According to Oxford Companion to WWII (Dear, et al., 1995, p. 434), of about 200,000 troops only around 50,000 survived Stalingrad. Between March 43 and March 44 the (Glantz et al., 1995) data implies 50,000, while divisional totals from (Ellis, 1993, p. 178) suggest 50,000 at the start growing to 100,000 by the end of this period (assuming small 10,000 divisions). I opt for the divisional totals, interpolating growth throughout this period. Data from March 1944 to March 1945 taken from Appendix Table C of When Titans Clashed. For April and May I assume loss ratio in proportion to German losses. Total Hungarian deaths and missing taken from (Stark, 1995, p. 33). Monthly totals are not available, so these are estimated to occur in proportion to the rate of German losses per month, adjusted by Hungarian force strength in that month.

Slovakia

Initially two divisions fought in the east, however the first division was disbanded in June 1944 following heavy losses in the Ukraine, and the second in October 1943. Total Slovak losses taken via wikipedia from Erlikman, Vadim (2004). Monthly series estimated as per the other nations.

Spain

The roughly 20,000-strong Blue Division fought until being withdrawn in October 1943. A remnant of about 3,000 remained with German forces until being fully withdrawn in March 1944. Total casualties taken via wikipedia from (Clodfelter, 2017). Monthly series estimated as per the other nations.

Finland

Initial strength in 1941 from (Tuunainen, 2012, p. 153). After September 1941, the full Finnish strength is not included in Axis totals, as the 'phoney war' between the Finns and the Soviets involved no offensives and only minimal action. Many soldiers were even given leave to do farming, see (Tuunainen, 2012, pp. 158-159). Actual effective combat strength engaged against the enemy between October 1941 and May 1944 was estimated based on Finnish casualties relative to those suffered during July/August 1941, when the whole army was engaged. Strength at beginning of Vyborg–Petrozavodsk Offensive in July 44 was taken from Wikipedia (see here), ultimately using the source (Zolotarev, 1999, p. 13). Monthly casualties taken from the Finnish online resource, Suomen sodissa 1939-1945 menehtyneet, http://kronos.narc.fi/menehtyneet/index.php.

Eastern Front Simulation

The purpose of the simulation is to test different hypotheses about the major factors contributing to Soviet victory on the eastern front. In particular, the aim was to determine:

- How close the Germans came to victory.
- How important was the contribution of the Western Allies.
- The significance of the German defeat at Stalingrad.
- How much manpower reserves affected the course of the fighting.

Structure of the simulation

The simulation was written as a python 2.7 script. The core of the simulation operates as follows:

1. Load actual manpower, strengths, reinforcements, losses, and ratio values from data files.
2. Initialise the corresponding variables to their values at the starting month of the simulation (by default this is April 1942).
3. For each month while the surrender conditions have not been met:
    a. Calculate the strength ratio (Soviet strength / German strength).
    b. Using the strength ratio and the loss ratio regression parameters, randomly sample a value for the loss ratio (Soviet losses / German losses).
    c. Using the strength ratio and the advance rate regression parameters, randomly sample a value for the advance rate (see table for definition).
    d. Using the advance rate and the total loss regression parameters, randomly sample a value for the total losses (German losses + Soviet losses). This is a measure of the overall intensity of the fighting.
    e. Update the strengths for the next month based on losses, reinforcements, and ratios for each combatant, incorporating changes to reinforcements to Soviets from the advance.
4. When the surrender condition is met, total the losses for each combatant and print these totals, along with the length of the war.

Additional aspects of the simulation are explained below.

- The simulation was terminated when either June 1947 was reached (six years from the German invasion), or when one combatant had a strength six or more times that of the other, or when either combatant has reached their maximum allowable advance.
- In order to prevent implausibly large frontline strengths that would be logistically implausible, the maximum possible Soviet strength was set to 7 million, and that for Germany was set for 3.4 million, but just slightly above the maximum strengths they achieved during the war.
- Every month after April 1942, 30,000 is deducted from the Soviet manpower total to incorporate the number of Soviet personnel discharged from the armed forces during the war (not due to wounds). This is based on my estimate of about 1.5 million non-wounded Soviet recruits discharged from any military role during the war, derived from Krivosheev's discharge data and my estimates of how many of those discharged were wounded, later killed, reconscripted, or moved into another military role.
- To account for the months in which no significant advances occurred, when the strength ratio is between 1.5 and 2.5 there is a 0.6 probability of no advance occurring. These parameters are based on the empirical data.
- Minor Axis and Allied forces are not included in the simulation. I experimented with including them, but there proved to be no rational and consistent way to do this without making many

arbitrary assumptions. Aside from the lack of data about their losses, the size of their forces on the front was predominantly determined by political factors, rather than the availability of reserves. As such, they could not be modelled in the same way as Germany and the Soviet Union. Also, even when forces were available, they were not always involved in active combat, such as most of the Finnish forces after 1941, and the Romanian home guard forces in 1944. As such their inclusion results in a poorer fit to the data, and distorts rather than enhances the military picture. Furthermore, minor axis nations never contributed more than 20-25% of German manpower in the east (excluding inactive Finnish forces), and this is without adjusting for the inferior quality of these forces. In Enduring the Whirlwind, Gregory Liedtke mentions that around the time of Stalingrad, Romanian, Italian, and Hungarian forces were probably about equal in capability to Soviet armies of comparable size. If this is true, then by my estimates this would place them between 10-50% as proficient as German forces, depending on how the estimate is made. As such I do not believe that minor axis forces made a major contribution to the German war effort. Their impact is implicitly incorporated into the parameters used in the simulation, slightly elevating German effectiveness in late 1942, and slightly elevating Soviet effectiveness in the last ten months of the war, when their minor allies made their largest contribution.

Variable definitions

Key variables used in the simulation are defined as follows. Note that the mean value is defined over actual historical data. In the simulation, these variables are set to their historical values only at the first month of the simulation, after which time the variables evolve according to the simulation.

Variable	Description	Mean
Soviet manpower	Total personnel in Soviet armed forces, including reserves and non-combatants. Excludes various paramilitary organisations such as NKVD, local antiair units, and paramilitary guards.	12.3 mil
German manpower	Total personnel in German armed forces, including Heer, Luftwaffe, Kreigsmarine, Waffen-SS, Ersatzheer, and civilians in armed forces. Excludes Volkssturm, police, Hitler Youth, and other paramilitary units.	10.4 mil
Soviet strength	Strength of Soviet armed forces deployed against Germany.	6.1 mil
German strength	Strength of all German armed forces deployed in the field on the Eastern Front.	2.5 mil
Soviet reinforcements	The number of personnel added to the Soviet manpower in each month.	0.40 mil
German reinforcements	The number of personnel added to the German manpower in each month.	0.16 mil
Soviet ratio	The ratio between Soviet manpower and Soviet strength. This is used to estimate how many personnel the Soviet Union could deploy on the field against Germany.	2.02
German ratio	The ratio between German manpower and German strength. This is used to estimate how many personnel Germany could deploy on the field against the Soviet Union.	4.32
Advance distance	Measures the area in square km occupied by Germany/Soviet Union relative to April 1942. The maximum value is 1,600,000, representing remaining German advance up to the AA line. The lowest value is -2,100,000, which is the total area the Soviets would liberate/capture between April 1942 and May 1945.	NA

Advance rates and occupation

In order to measure the rate at which territory is captured, it was necessary to collect data concerning the area and also populations of Eastern Europe. This is also important to determine how many additional recruits were available to the Soviet Union upon liberation of occupied territories, which was an important source of manpower in the second half of 1943 and in 1944.

Area and populations

Areas and populations of Soviet and Eastern/Central European regions were derived from a variety of sources. Regional areas and populations for Russia in 1939 were taken from Populstat (see archive here). Ukrainian regional populations are not available for 1939 from this source, but are available for 1959. Thus, the total Ukrainian population for 1939 was taken from (Vallin et al., 2002, p. 257), and the regional values then adjusted backways from the 1959 regional populations using the 1939 total. Regional proportions were extrapolated from 1959 Populstat data. No total was available for Belarus in 1939, however it is estimated to be little different to 1959 owing to WWII losses, and so the 1959 population values were used. Note that Ukrainian and Belorussian data include areas annexed in 1939/40. The population of the Baltic states and Moldova in 1939 was taken from (Sužiedelis, 1981). Areas of statistical regions in Hungary and Poland taken from modern EU data (see e.g. for Poland). Areas of Yugoslavia provinces taken from (Rothschild, 2017, p. 238). Area of Soviet occupation of Germany at war's end is estimated as roughly Brandenburg, Berlin, Saxony, and Mecklenburg-Vorpommern, also taken from EU data.

Occupation timeline

A timeline of the occupation of Central and Eastern Europe by German and Soviet forces was prepared using a variety of maps, particularly the Atlas of the World Battle Fronts in Semimonthly Phases, and the West Point Atlas of the Second World War: Europe and the Mediterranean. Several Youtube videos were also consulted for this purpose, especially for details of German advances during Barbarossa. A spreadsheet was constructed, showing at the start of each month from June 1941 to May 1945, whether Germany or Soviet forces occupied each of the identified regions in Central and Eastern Europe. Obviously, advances do not neatly correspond to provincial boundaries, so approximations were made for territories overlapping the front line. When appropriate, fractions of 0.75, 0.50, or 0.25 were used based on visual inspection of the maps.

For Soviet territories, the estimated fraction of all German occupied territories was then multiplied by the estimated 1939 population, to yield an overall estimate of the population of German occupied territories at the start of each month. While this method is somewhat crude, it is expected to not yield errors more than around 5-10%, which should be sufficient for the purpose. The primary importance of these data is to provide estimates for the number of potential military recruits available in German occupied territory. This became a very important source of manpower for the Soviet military during late 1943 and throughout 1944.

Liberated Soviet recruits

Total population estimates of occupied territories were then converted to number of estimated available recruits using a figure taken from 'The Price of Victory' Appendix C: Mobilisation Report, where 6.299 million potential recruits (including those from Baltics and Moldova) in German occupied territories are reported as not having been called up as at 1 Sep 1942. It is assumed (unrealistically but without any other alternative), that these recruits were distributed proportional to the population of the occupied Soviet territories. However, for the purpose of the simulation it is necessary to have an estimate of the number of Soviet recruits made available per square km of territory recaptured, because the simulation

keeps track only of total territory, not specific regions, or the populations thereof. As such, using the recruit estimates constructed as described in this paragraph, a scatterplot was constructed of the territory liberated by the Soviet Union against the number of recruits gained from that territory (based on the actual territories liberated, not a simulation). Fitting a linear regression model yielded an R-squared value of 0.922, indicating that the number of recruits liberated is very well approximated by the amount of area captured. The coefficient of this regression this provided the parameter value of 3.93 recruits gained on average per square km of liberated Soviet territory.

Parameter regressions

Loss ratio regression results

The loss ratio is estimated using parameters found by regressing the logarithm of the Soviet/German loss ratio against the logarithm of the Soviet/German strength ratio. Note that only Soviet and German strengths and losses are used, because the strength of Soviet and German allies depends mostly on political factors which cannot meaningfully be incorporated into the simulation.

$$SR = \ln\left(\frac{\text{Soviet strength}}{\text{German strength}}\right)$$

$$LR = \ln\left(\frac{\text{Soviet losses}}{\text{German losses}}\right)$$

$$\hat{\mu}_{LR} = \hat{\alpha}_{SR,LR} + \hat{\beta}_{SR,LR} \times SR$$

$$\hat{\sigma}_{LR} = se_{LR,SR} \times \sqrt{1 + \frac{1}{n} + \frac{(SR - \mu_{SR})^2}{\sum(SR_i - \mu_{SR})^2}}$$

$$LR \sim N(\hat{\mu}_{LR}, \hat{\sigma}_{LR})$$

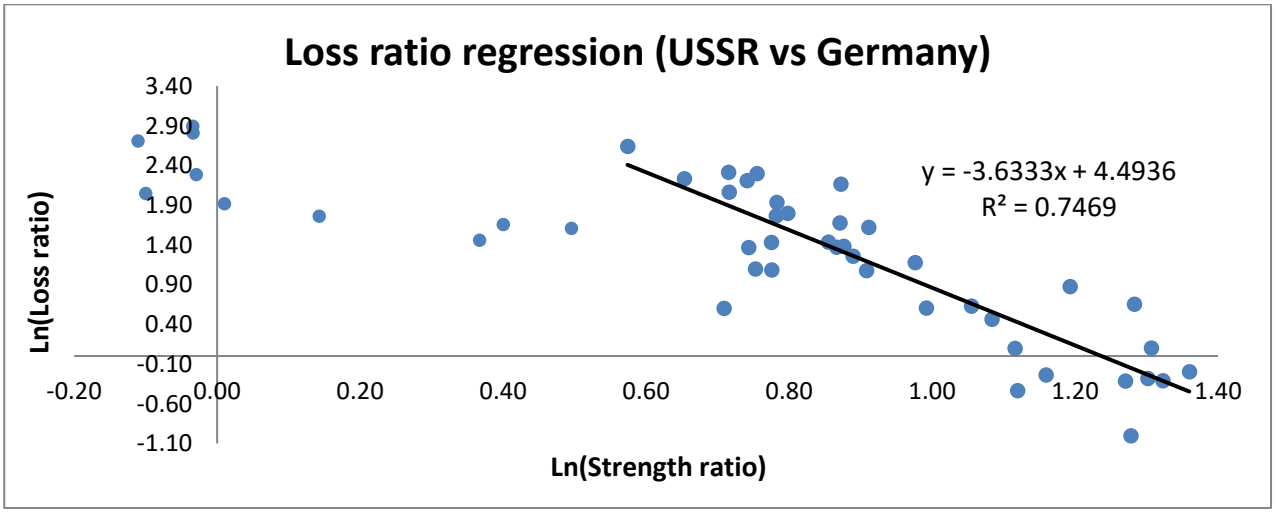
Regression Statistics	
Multiple R	0.864
R Square	0.747
Adj R Square	0.740
Standard Error	0.481
Observations	37

$se_{LR,SR}$	μ_{SR}	$SS(SR)$
0.481	0.950	1.811

ANOVA

	df	*SS*	*MS*	*F*	*P-value*
Regression	1	23.901	23.901	103	0.0000
Residual	35	8.100	0.231		
Total	36	32.001			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
$\hat{\alpha}_{LR,SR}$	4.494	0.349	12.889	0.000	3.786	5.201
$\hat{\beta}_{LR,SR}$	-3.633	0.358	-10.162	0.000	-4.359	-2.907



Advance rate regression results

The advance rate in square km is estimated using parameters found by regressing the monthly change in territory (in square km, negative numbers indicating Soviets retaking territory) against the logarithm of the Soviet/German strength ratio. Note that although the R-squared is not high, there is enough regularity to provide a signal to the simulation. There is, however, a great deal of variation, which can be interpretated as variation at the operational level.

$$SR = \ln\left(\frac{\text{Soviet strength}}{\text{German strength}}\right)$$

$$AR = \text{Area advanced}_{t+1} - \text{Area advanced}_{t}$$

$$\hat{\mu}_{AR} = \hat{\alpha}_{AR,SR} + \hat{\beta}_{AR,SR} \times SR$$

$$\hat{\sigma}_{AR} = se_{AR,SR} \times \sqrt{1 + \frac{1}{n} + \frac{(SR - \mu_{SR})^2}{\sum(SR_i - \mu_{SR})^2}}$$

$$AR \sim N(\hat{\mu}_{AR}, \hat{\sigma}_{AR})$$

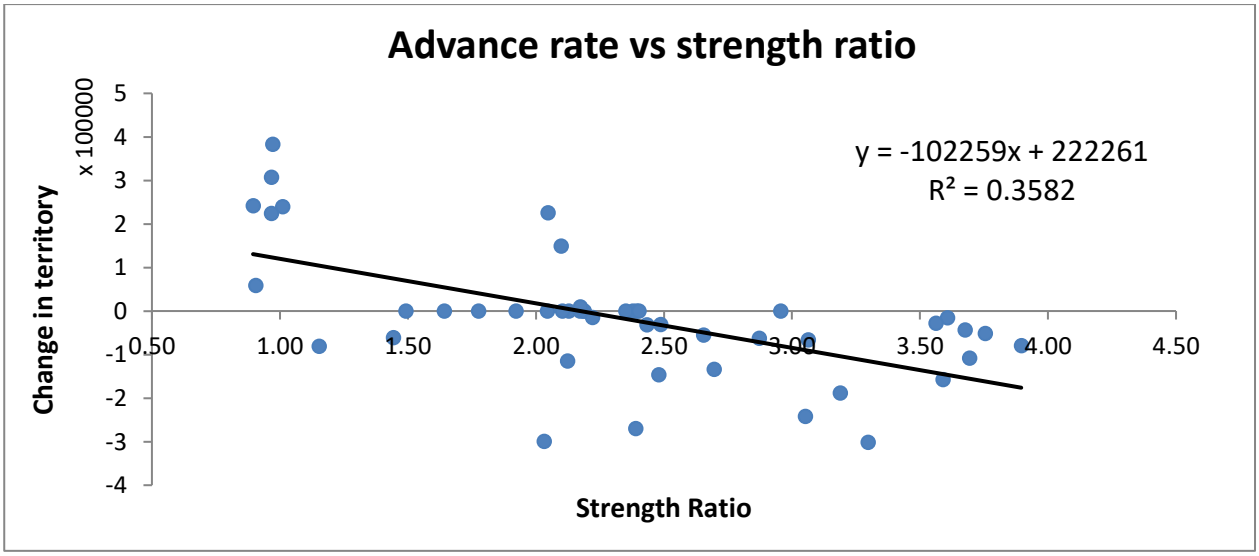
Regression Statistics	
Multiple R	0.609
R Square	0.371
Adj R Square	0.357
Standard Error	114,914
Observations	48

$se_{AR,SR}$	μ_{SR}	$SS(SR)$
114,914	2.330	32.372

ANOVA

	df	*SS*	*MS*	*F*	*P-value*
Regression	1	3.58E+11	3.58E+11	27.08	4.42E-06
Residual	46	6.07E+11	1.32E+10		
Total	47	9.65E+11			

Parameter	*Coefficient*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
$\hat{\alpha}_{AR,SR}$	219,383	48,719	4.503	0.000	121,316	317,451
$\hat{\beta}_{AR,SR}$	-100,765	19,363	-5.204	0.000	-139,741	-61,789



Total losses regression results

The total monthly losses (Soviet and German together) is estimated using parameters found by regressing the total monthly losses against the monthly change in territory (in square km, negative numbers indicating Soviets retaking territory). Note that although the R-squared is not high, there is enough regularity to provide a signal to the simulation. The total area advanced was used to predict total losses as the best available proxy for the 'intensity' of the fighting.

$$TL = \text{Soviet losses} + \text{German losses}$$
$$AR = \text{Area advanced}_{t+1} - \text{Area advanced}_{t}$$

$$\hat{\mu}_{TL} = \hat{\alpha}_{TL,AR} + \hat{\beta}_{TL,AR} \times AR$$
$$\hat{\sigma}_{TL} = se_{TL,AR} \times \sqrt{1 + \frac{1}{n} + \frac{(AR - \mu_{TL})^2}{\sum(AR_i - \mu_{TL})^2}}$$
$$AR \sim N(\hat{\mu}_{TL}, \hat{\sigma}_{TL})$$

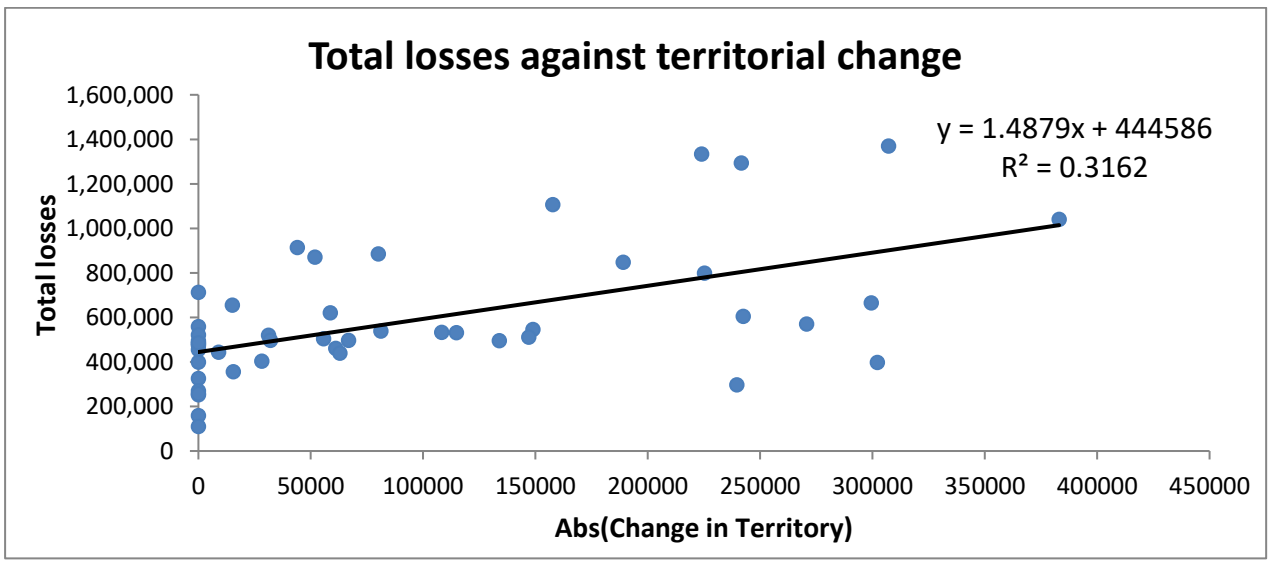
Regression Statistics	
Multiple R	0.562
R Square	0.316
Adj R Square	0.301
Standard Error	239,716
Observations	47

$se_{TL,AR}$	μ_{AR}	$SS(AR)$
239,716	94,187	5.40E+11

ANOVA

	df	*SS*	*MS*	*F*	*P-value*
Regression	1	1.196E+12	1.195E+12	20.81	3.89-05
Residual	45	2.586E+12	5.75E+10		
Total	46	3.782E+12			

Parameter	*Coefficient*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
$\hat{\alpha}_{TL,AR}$	444,586	46,544	9.552	0.000	350,842	538,330
$\hat{\beta}_{TL,AR}$	1.488	0.326	4.562	0.000	0.831	2.145



Simulation Configuations

The following simulation variations were examined.

Simulation Mode	Description	Purpose
Standard	Historical German Additional Losses and Eastern Front Ratio.	Attempt to replicate historical outcome.
No Surrender	Historical German Additional Losses and ratios until Feb 1945; thereafter 227,000 Additional Losses (average since Jul 1944) and Eastern Front Ratio of 4.50.	Prevent the simulation always ending around April 1945 due to massive surrenders in the West.
No West	Historical German Additional Losses and ratios until Oct 1942; thereafter 8,000 Additional Losses and Eastern Front Ratio of 2.94 (both average of Nov 41 to Oct 42).	Counterfactual to estimate what would happen if the West maintained its force level against Germany at pre-Torch levels for the remainder of the war.
Late Torch	Historical German Additional Losses and ratios until Oct 1942; thereafter 8,000 (average of Nov 41 to Oct 42) Additional Losses, and Eastern Front Ratio of 3.13 (average May to Oct).	Counterfactual to estimate what would happen if the West maintained its force level against Germany at pre-Torch levels for an additional year.
Failed D-Day 12 months	Historical German Additional Losses and ratios until June 1944, then repeating the values from Jul 43 – Jul 44 for the next year, then resuming historical values of Jul 44.	Counterfactual to estimate what would happen if Operation Overlord failed and it took another year before the Western Allies were able to mount a second attempt.
Failed D-Day 9 months	Historical German Additional Losses and ratios until June 1944, then repeating the values from Oct 43 – Jul 44 for the next nine months, then resuming historical values of Jul 44.	Counterfactual to estimate what would happen if Operation Overlord failed and it took nine months before the Western Allies were able to mount a second attempt.
Early Mobilisation	Assumes that Germany mobilised an addition 1 million men in 1941, and correspondingly less in 42-44. This allows a higher strength on the Eastern front: 3.1 million by Apr 42 in the ‘modest’ case, and 3.3 million by Jun 42 in the ‘major’ case.	Counterfactual to estimate the effect of inadequate German mobilisation and training during 1941 had on the ability to rebuild after the losses of Barbarossa and the Soviet winter offensive. Changes the timing of recruitment but not the number.

Analysis and Discussion

The results for running the relevant simulation 10,000 times at the specified starting date are shown in the figure below. The simulation data are shown as dotes, and a sigmoid fitted through the points is shown as a line. The y-axis shows the probability of Germany achieving victory against the Soviet Union by mid-1947, given the military actual historical situation as specified at the time marked on the x-axis, but with the adjustment made in accordance with the specified situation. Results of the simulations indicate that the pressure of the West was critical for the defeat of Nazi Germany, and also that greater mobilisation during 1940-41 could have made a significant difference in the campaign against the Soviet Union in 1942-43.

On Soviet loss rates:

> "The Russians did enjoy a two-to-one margin and more in select areas, but it was not enough to overwhelm the Germans with manpower alone. The Russians sustained 11.3 million killed and captured, compared to over 3 million Germans plus their Allies killed on the Eastern Front. Most of the Russian losses (6 million) were sustained in the first 15 months of the war, while German losses in that period were low. For the remainder of the war, losses of two-to-one were the price of attacking a highly proficient defender." (Dunn, 1995, p. 198)

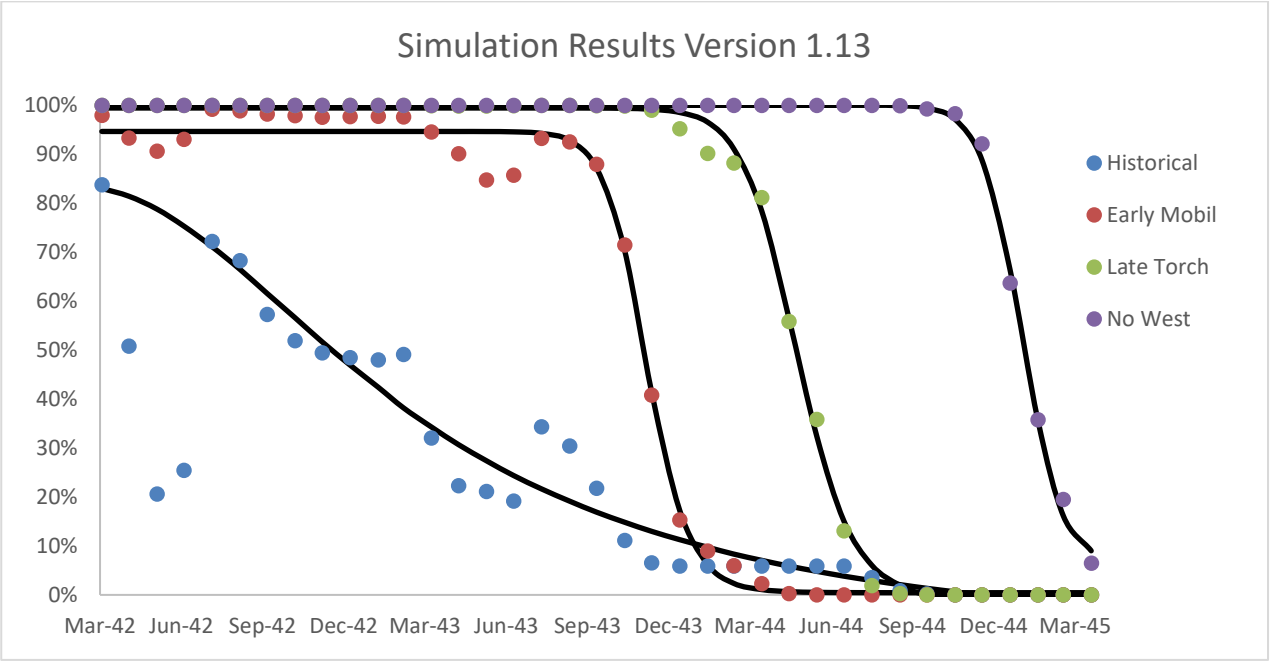
> "The Soviets, like the Germans, suffered from severe manpower shortages. The staggering civilian and military casualties of the war, the large factories needed to maintain weapons production, and the demands of rebuilding a shattered economy in land reclaimed from the Germans all strained the supposedly inexhaustible supply of Soviet manpower… By 1944, the Red Army faced a manpower crisis that was, in its own way, as serious as that confronting the Wehrmacht. Many rifle divisions had an effective strength of 2,000 or less." (Glantz, et al., 1995)

On German assumptions regarding Operation Barbarossa:

> "The economic leadership thus relied totally on the success of Germany's military planning for the war. They neglected to mobilise those reserves which were still available for the war in the east, and failed to combat frictions within the war economy which were often caused by sheer weakness of organisation." (Boog et al., 1999, p. 1083)

> "After an exhausted Army Group Centre ground to a standstill before Moscow at the beginning of December 1941, Hitler ordered an increase in German armaments production. He had apparently recognised that the period of Blitzkrieg was over, and that Germany faced a long war of attrition." (Boog, et al., 1999, p. 1182)

> "In line with their confident expectation of speedy and decisive victory, the Third Reich calibrated its attack on the Soviet Union so that as many resources as possible could be freed at the earliest opportunity for the ongoing struggle with Britain and its backers in the United States." (Tooze, 2006, p. 430)



An analysis of the data yields two clear conclusions. The first is that German plans for a quick victory over the Soviet Union were woefully unrealistic. Even had more preparation been made for a long conflict, Germany had no realistic hope of defeating the Soviet Union in fewer than three years. The second is that the performance of the Soviet military was extremely poor. The Soviet Union was only able to inflict a 1:1 casualty ratio in the last 10 months of the war, at a time when the Wehrmacht had lost air superiority, was severely hampered by fuel and other key shortages, and were outnumbered on the Eastern front more than 3:1.

References

Abbott, P. (1982). *Germany's Eastern Front Allies 1941-45*: Osprey Publishing.

Askey, N. (2018). *Operation Barbarossa: the Complete Organisational and Statistical Analysis, and Military Simulation Volume IIB*: Lulu.com.

Axworthy, M., Scafeș, C. I., & Craciunoiu, C. (1995). *Third Axis, Fourth Ally: Romanian Armed Forces in the European War, 1941-1945*: Arms and Armour.

Boog, H., Forster, J., Hoffman, J., Klink, E., et al. (1999). *Germany and the Second World War. Volume IV: The Attack on the Soviet Union* (Vol. 4): Clarendon Press.

Boog, H., Rahn, W., Stumpf, R., Wegner, B., et al. (2001). *Germany and the Second World War. Volume VI: The Global War* (Vol. 6).

Clodfelter, M. (2017). *Warfare and armed conflicts: A statistical encyclopedia of casualty and other figures, 1492-2015*: McFarland.

Dear, C., & Foot, M. (1995). The Oxford Companion to World War II: Oxford University Press, Oxford.

Dunn, W. S. (1995). *The soviet economy and the Red Army, 1930-1945*: Greenwood Publishing Group.

Ellis, J. (1993). *The World War II databook : the essential facts and figures for all the combatants / John Ellis*. London: Aurum Press.

Ellman, M., & Maksudov, S. (1994). Soviet deaths in the Great Patriotic War: a note. *Europe-Asia Studies, 46*(4), 671-680.

Frieser, K.-H. (2017). *Germany and the Second World War. Volume VIII: The Eastern Front 1943-1944: The War in the East and on the Neighbouring Fronts* (Vol. 8).

Glantz, D. M., House, J. M., Grauberger, D., & McCleary, G. F. (1995). *When titans clashed: how the Red Army stopped Hitler*: University Press of Kansas Lawrence.

Ismailov, A. I. (2011). On the issue of human losses during the Great Patriotic War, 1941–1945. *Journal of Slavic Military Studies, 24*(2), 232-237.

Istituto Centrale di Statistica. (1957). Morti e dispersi per cause belliche negli anni 1940–45: Repubblica Italiana, Istituto Centrale di Statistica Rome.

Kroener, B. R., Muller, R.-D., & Umbreit, H. (2000). *Germany and the Second World War. Volume V: Organization and Mobilization of the German Sphere of Power. Part I: Wartime Administration, Economy, and Manpower Resources, 1939-1941*: Claredon Press.

Kroener, B. R., Müller, R.-D., & Umbreit, H. (2003). *Germany and the Second World War. Volume V: Organization and Mobilization of the German Sphere of Power. Part 2. Wartime Administration, Economy, and Manpower Resources, 1942-1944/5* (Vol. 5): Clarendon.

Lopukhovsky, L., & Kavalerchik, B. (2017). *The Price of Victory: The Red Army's Casualties in the Great Patriotic War*: Casemate Publishers.

Marshall, G. C. (1996). *Biennial Reports of the Chief of Staff of the United States Army to the Secretary of War. 1 July 1939 - 30 June 1945*: Center of Military History, United States Army.

Mueller-Hillebrand, B. (1969). *Das Heer 1933-1945. Entwicklung des organisatorischen Aufbaues. Band III: Der Zweifrontenkrieg.* : E. S. Mittler & Sohn.

Multari, S. M. Seconda Guerra Mondiale - I Caduti del Fronte Orientale.

Overmans, R. (2009). *Deutsche militärische Verluste im Zweiten Weltkrieg* (Vol. 46): Walter de Gruyter.

Overmans, R., & Goeken-Haidl, U. (2000). *Soldaten hinter Stacheldraht: deutsche Kriegsgefangene des Zweiten Weltkriegs*: Propyläen.

Rothschild, J. (2017). *East Central Europe between the two world wars*: University of Washington Press.

SHAEF. (1945). *Supreme Headquarters Allied Expeditionary Force (SHAEF): weekly intelligence summary No 51*. Retrieved from https://discovery.nationalarchives.gov.uk/details/r/C11131550.

Sokolov, B. (2013). *The Role of the Soviet Union in the Second World War: A Re-Examination*: Helion Studies in Military His.

Sorge, M. K. (1986). *The other price of Hitler's war: German military and civilian losses resulting from World War II*: Greenwood Publishing Group.

Stark, T. (1995). *Hungary's human losses in World War II*: Centre for Multiethnic Research [Centrum för multietnisk forskning], Univ.

Statiev, A. (2010). Penal Units in the Red Army. *Europe-Asia Studies, 62*(5), 721-747.

Stein, G. H. (1984). *The Waffen SS: Hitler's elite guard at war, 1939-1945*: Cornell University Press.

Sužiedelis, S. (1981). On OSS report on wartime population changes in the Baltic. *Lituanus, 27*(3).
Tooze, A. (2006). *The wages of destruction: The making and breaking of the Nazi economy* (Vol. 115).
Tuunainen, P. (2012). *The Finnish army at war: Operations and soldiers, 1939–45*: Brill.
Ufficio storico dello Stato Maggiore dell'Esercito (USSME). (1993). *Le operazioni in Sicilia e in Calabria*.
Vallin, J., Meslé, F., Adamets, S., & Pyrozhkov, S. (2002). A New Estimate of Ukrainian Population Losses during the Crises of the 1930s and 1940s. *Population Studies, 56*(3), 249-264.
Zolotarev, V. (1999). *Русский архив: Великая Отечественная. Ставка ВКГ: Документы и материалы 1944–1945* (Vol. 16). Moscow.
Кривошеев, Г. Ф. (2010). *Великая Отечественная без грифа секретности. Книга потерь*.
Суринов, А., & Оксенойт, Г. (2015). *Великая Отечественная война. Юбилейный статистический сборник*.