Global industrial disruption following nuclear war

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Abstract

Nuclear war poses catastrophic risks not only through its immediate effects and potential nuclear winter, but also through the disruption of industrial production on which modern civilization depends. In this study we estimate the reduction in global industrial output following a US-Russia nuclear war, as well as a more limited India-Pakistan exchange, by combining geospatial analysis with historical evidence of how localized industrial losses propagate through supply chains. A bilateral US-Russia nuclear war could destroy 3% of global industrial infrastructure, with cascading effects potentially reducing global industrial output by 25%. If high-altitude electromagnetic pulse attacks occur, the disruption to global industry could be even more severe, though such effects remain poorly understood. These disruptions would severely impair humanity's ability to meet basic needs and adapt to other nuclear war effects such as nuclear winter.

Introduction

A large-scale nuclear war would cause unprecedented destruction, with immediate casualties numbering in the tens or hundreds of millions (*1*–*3*). However, the greatest threats to the continued existence of modern human civilization lie not in the direct effects of the explosions, but in their long-term, global consequences (*3*, *4*). Nuclear winter—where stratospheric soot from urban firestorms could reduce sunlight and agricultural productivity for years—represents a major risk that has received significant research attention (*3*, *5*–*8*). Another critical yet understudied risk is Global Catastrophic Infrastructure Loss (GCIL).

Historical evidence from previous conflicts suggests that in a nuclear war, critical industrial infrastructure such as ports and oil refineries would likely be targeted (*9*). Even if not directly targeted, a portion of this vital infrastructure could be destroyed as collateral damage from attacks on nearby urban centers. The loss of these industrial assets could severely impair humanity's ability to meet its basic needs (*10*, *11*). In particular, modern agriculture is heavily reliant on industrial inputs such as fuel, fertilizers and pesticides (*12*, *13*), meaning that a decrease in industrial capacity would exacerbate the agricultural challenges posed by nuclear winter (*14*). Beyond agricultural production, the entire food supply chain also depends on functional industrial infrastructure (*15*).

Modern industry relies on complex supply chains where the output of each facility depends on inputs from numerous others. Through these linkages, shocks to one industry or region can propagate throughout the economy (*16*–*20*), and these ripple effects can extend far beyond national borders through international supply chains (*21*–*24*). These interdependencies suggest that the impact of nuclear war on industrial production could extend well beyond the directly damaged areas.

This study quantifies the extent of industry loss resulting from nuclear war through a three-step approach. First, we establish scaling relationships between nuclear weapon yield and destruction radius. Second, we use OpenStreetMap industrial infrastructure data to calculate the fraction of industrial assets destroyed in two different nuclear exchange scenarios. Finally, we examine historical analogues—from natural disasters to conventional warfare—to estimate how direct infrastructure losses propagate through supply chains to affect total industrial output.

Results

Nuclear weapons effects on infrastructure

The atomic bombings of Hiroshima and Nagasaki remain the most reliable reference points for understanding the destructive capacity of nuclear detonations. In Hiroshima, a 15 kt weapon destroyed 13 km^2 of the city, while in Nagasaki, a 21 kt weapon destroyed 6.7 km^2 (*25*, *26*). In both cases, the buildings completely destroyed by blast alone (without fire) represented less than 10% of all the completely destroyed buildings, making the burn region a good approximation of the overall destruction zone (*26*). To estimate the effects of modern nuclear weapons, which typically have yields in the hundreds of kilotons (kt), we need to scale up from these historical data points.

Nuclear weapons destroy infrastructure through blast effects and fires. The blast damage radius scales with yield Y as $R \propto Y^{1/3}$ (*27*). Fires can be ignited both by thermal radiation and as secondary effects of blast damage (e.g., ruptured gas lines) (*28*). Without atmospheric attenuation, the radius at which thermal radiation could ignite fires would scale as $R \propto Y^{1/2}$, but the atmosphere reduces this range (*27*).

To determine how the destruction radius scales with yield, we combined data from Hiroshima and Nagasaki with modeled burn areas from higher-yield detonations (50 kt and 1 Mt) that account for both thermal and blast-induced fires (*29*). This yields a best-fit power law scaling of $R = 0.75 \times Y^{0.38}$, where R is the radius of the area destroyed in km and Y is the yield in kt (Fig. 1). This intermediate exponent reflects the combined effects of blast damage, thermal radiation, and atmospheric attenuation. Given that the burn area closely approximates the total destroyed area in Hiroshima and Nagasaki, and that burn area scales more rapidly with yield than blast effects, the burn area should be an even better approximation of total destruction for higher-yield weapons.

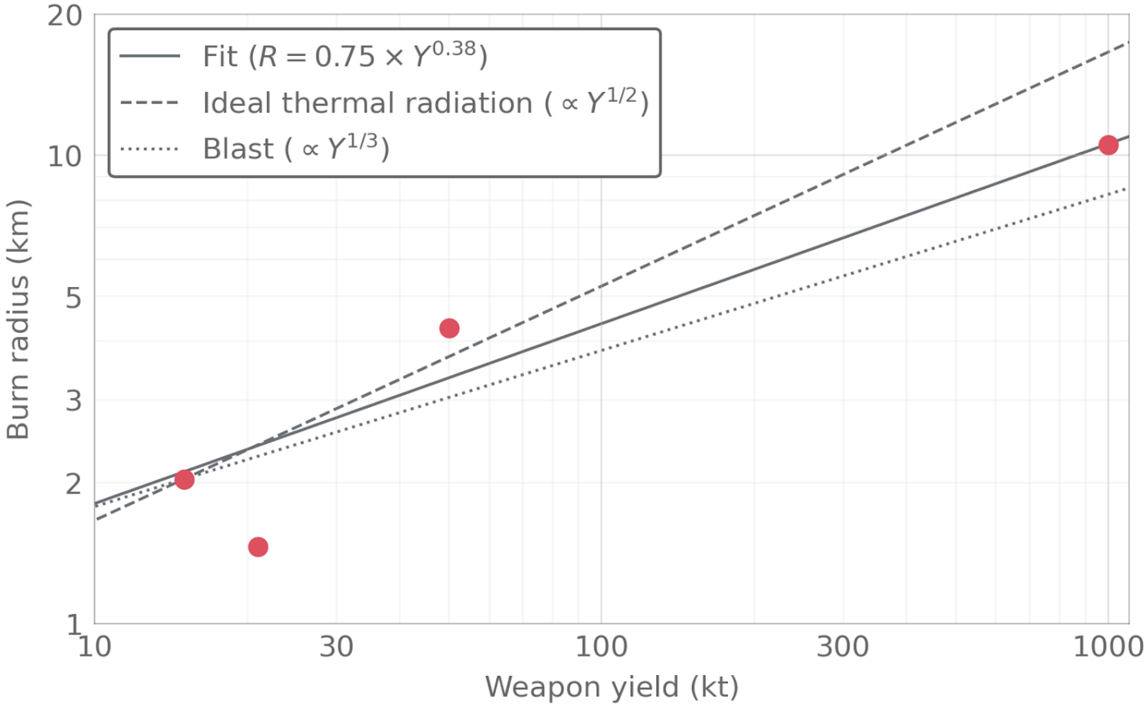

Fig. 1 Scaling relationships between nuclear weapon yield and burn radius. Red dots represent empirical and modeled data points: two from the atomic bombings of Japan (15 kt and 21 kt) and two from the modeling of 50 kt and 1 Mt detonations (*29*). The solid line shows our best-fit power law scaling ($R = 0.75 \times Y^{0.38}$), which lies between the blast damage scaling ($R \propto Y^{1/3}$, dotted line) and the ideal thermal radiation scaling ($R \propto Y^{1/2}$, dashed line). We extracted the high-yield data points from ref. (*29*), taking the distances from ground zero where the fire damage probability reaches 50% in their mean damage model.

We derived this scaling relation from air-burst detonations, which we expect to account for most industrial destruction in a nuclear conflict. Ground bursts are likely to be reserved primarily for strikes against hardened military assets, where their ability to transmit more blast energy to their targets outweighs their smaller overall destruction radius. Note that air bursts generally produce little radioactive contamination (*27*), as evidenced by the fact that Hiroshima and Nagasaki were continuously inhabited. Therefore, radioactive fallout from air bursts is unlikely to significantly impact industrial activities beyond the immediate destruction zone, and we neglected this effect in this work.

Industrial infrastructure assessment

We used OpenStreetMap (OSM) data (*30*, *31*) to identify industrial assets and estimate infrastructure losses from nuclear detonations. Our validation against reference datasets found that 99% of known oil refineries and 95% of fertilizer and pesticide manufacturing facilities in countries considered below were correctly tagged as industrial zones in the OSM data, confirming sufficient completeness for our analysis. For each simulated detonation, we calculated the overlap between its destruction radius and industrial areas (Fig. 2), allowing us to estimate the fraction of industrial infrastructure destroyed in different scenarios.

Fig. 2 Example application of industrial damage assessment methodology. The red circle represents the predicted destruction radius for a 300 kt detonation over the Port of Rotterdam. Industrial zones from OpenStreetMap are shown as polygons, with hatched areas indicating zones considered destroyed based on their intersection with the destruction radius.

Historical patterns of industrial disruption

To estimate how direct infrastructure losses propagate through supply chains to affect total industrial output, we analyzed historical examples and economic models of hypothetical scenarios (see Materials and Methods for details). These cases range from natural disasters to wartime destruction, providing insights into how industrial systems respond to different scales of disruption.

Our analysis shows that total industrial output falls by several times the fraction of infrastructure directly destroyed (Fig. 3). While each case involves confounding factors beyond direct infrastructure loss—such as transportation disruptions, trade embargoes, labor shortages, and financial shocks—similar compounding effects would likely accompany nuclear conflict. This suggests these historical examples, while imperfect parallels, provide reasonable empirical benchmarks for estimating potential impacts.

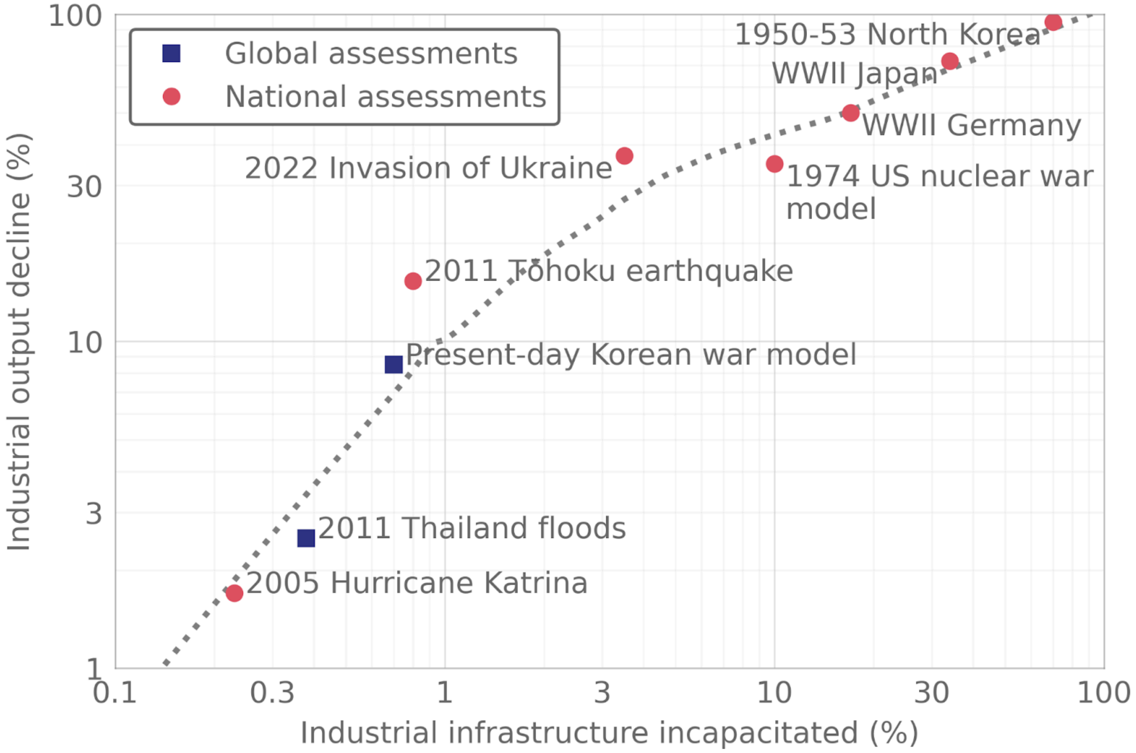

Fig. 3 Relationship between industrial infrastructure incapacitated and industrial output decline across historical events and model assessments. Blue squares represent global-scale assessments, where both the incapacitation and output decline are measured at the worldwide level, while red circles represent national-scale assessments. Data points include natural disasters, wartime destruction, and economic models of hypothetical scenarios. All cases involve compounding factors beyond direct infrastructure loss, such as transportation disruptions, labor shortages, and financial shocks—conditions likely to accompany nuclear conflict as well. The dotted line shows a locally weighted (LOESS) regression fit to illustrate the general trend.

India-Pakistan nuclear war

Pakistan and India possess approximately 170 nuclear warheads each, primarily in the 5-40 kt range (*32*, *33*). We modeled a scenario where each nation uses 50% of its arsenal against the other's population centers, with 15 kt warheads (*34*). This urban targeting assumption aligns with both nations' nuclear doctrines, which include countervalue elements targeting population centers (*35*, *36*). While the 50% usage rate is speculative, it aims to account for weapons that would fail to reach their targets, be used against military targets typically located away from industrial zones, or be held in strategic reserve—particularly relevant for India given its deterrence posture toward China (*37*). The remaining weapons were excluded from our industrial damage calculations.

Using LandScan 2022 population density data (*38*), we simulated the detonation of 85 warheads from each side, selecting target locations iteratively to maximize additional casualties. Our casualty estimation methodology follows Toon *et al.* (*39*) and yields 57 million immediate fatalities, consistent with their later assessment of an India-Pakistan exchange (*34*). This nuclear exchange would destroy 1.5% and 11% of the industrial capital of India and Pakistan, respectively. To estimate the impact on global industrial infrastructure, we weighted these losses by each country's contribution to the world's real industrial GDP— 7% for India and 0.6% for Pakistan (*40*)—yielding a 0.17% reduction in global industrial infrastructure.

For India's 1.5% industrial infrastructure loss, our empirical relationship (Fig. 3) suggests a 15% reduction in national industrial output, comparable to Japan's experience following the 2011 Tōhoku earthquake (*41*). For Pakistan's 11% infrastructure loss, the relationship points to a 45% reduction in national output. At the global level, the loss of 0.17% of worldwide industrial infrastructure corresponds to approximately a 1.3% reduction in global industrial output based on the regression fit in Fig. 3.

US-Russia nuclear war

We analyze a full-scale nuclear exchange between the United States and Russia using the counterforce+countervalue target list from OPEN-RISOP, a compilation of hypothetical Russian nuclear strike targets in the United States (*42*). This scenario employs 2,030 warheads—a plausible number given Russia's estimated arsenal of 2,822 strategic nuclear warheads, including 1,710 deployed (*43*). All 450 US intercontinental ballistic missile silos are targeted with 800 kt ground bursts. Most remaining targets receive warheads ranging from 100-250 kt. The target list encompasses military installations (118 military airfields, 107 military bases, 45 missile launch control centers), critical infrastructure (74 oil refineries, 47 dams, 29 cable landing stations), and civilian/government targets (131 city halls, 32 state capitols).

We estimated 45 million immediate fatalities in the United States from prompt radiation, blast and fires. Fallout from ground bursts against missile silos would cause additional deaths (*44*–*46*). Our analysis indicates that 24% of US industrial infrastructure would be destroyed. For Russian losses, lacking a comparable target map, we assume proportionally similar destruction. Weighting these losses by the US and Russian contributions to the world’s real industrial GDP yields a 3% reduction in global industrial capital.

Based on our empirical relationship (Fig. 3), a 24% loss of industrial infrastructure suggests 60% reductions in national industrial output for both countries, similar to the impacts of strategic bombing in World War II where Germany and Japan experienced 50-70% production declines following comparable infrastructure losses (*47*–*50*). At the global level, Fig. 3 suggests that disabling 3% of worldwide industrial infrastructure would reduce global industrial output by 25%.

Additional risk factors

Several mechanisms could amplify the industrial infrastructure loss beyond the direct blast and fire damage considered above. Some targets might be selected specifically for their potential to cause widespread collateral effects—for instance, strikes on major dams could trigger catastrophic flooding of industrial zones, while attacks on nuclear power plants and spent fuel storage facilities could create large radiological exclusion zones (*51*). Additionally, nuclear conflicts could easily expand beyond bilateral exchanges. In particular, a US-Russia nuclear exchange would likely involve other NATO states given the alliance's Article 5 mutual defense commitments.

High-altitude electromagnetic pulse (HEMP) attacks represent a particularly concerning amplification mechanism. A HEMP is produced when a nuclear weapon is detonated at high altitude (typically above 30 km), generating electromagnetic effects that can damage or disable electric and electronic equipment across vast areas. For example, a detonation at 500 km altitude over the central United States could affect most of North America (*27*). Modern industrial facilities depend heavily on HEMP-sensitive electronic systems (*52*), with even seemingly mechanical processes requiring electronic sensors, controllers, and communication networks. The most comprehensive unclassified HEMP risk assessment, the US EMP Commission report (*52*), concluded that long-term catastrophic damage across multiple critical infrastructures is possible but precise predictions remain out of reach due to limited real-world data (*53*).

Discussion

A regional nuclear war between India and Pakistan would likely have limited effects on global industrial output despite catastrophic regional humanitarian consequences and the potentially profound implications of breaking the nuclear taboo. A full-scale nuclear war between US and Russia could trigger much more extensive disruption, with cascading supply chain effects potentially reducing global industrial output by 25% or more.

This industrial disruption would compound other effects of nuclear war. Modern agriculture's dependence on industrial inputs means that reduced industrial capacity would exacerbate food security challenges posed by nuclear winter. Assuming a uniform 25% reduction across industrial sectors, the diminished production of agricultural inputs alone would reduce wheat and maize yields by approximately 15% (*12*). This loss of agricultural inputs represents just one of multiple channels through which food security would be threatened (*7*, *54*). GCIL would also impair humanity's ability to adapt to nuclear winter conditions through measures such as relocating agriculture or scaling up resilient food production (*8*, *55*).

Given its consequences, GCIL could contribute to nuclear deterrence. The cascading effects through supply chains mean that any nation initiating nuclear conflict risks devastating disruption to its own industrial base, even without suffering direct attacks. This extends beyond simple bilateral trade relationships: through multi-step dependencies in global supply networks, a country might be critically dependent on inputs from trading partners of its nuclear target. This additional deterrent effect is consistent with the historical observation that increased international trade correlates with reduced interstate conflict (*56*), and parallels proposed arguments about the deterrent effects of nuclear winter (*57*).

Several strategies could help mitigate GCIL risks. Standard supply chain resilience approaches, such as strategic stockpiling of critical industrial inputs and maintaining distributed manufacturing capabilities across regions, provide some protection. While comprehensive EMP hardening would be prohibitively expensive, protecting key facilities through measures like Faraday cage shielding and replacing copper signal cables with fiber optics could help preserve core industrial capabilities. Some US electric utilities have already implemented military-grade EMP protection at their transmission control centers (*58*).

Many aspects of post-nuclear war industrial disruption warrant further investigation. We treated industrial infrastructure loss as homogeneous, when different industries would in fact experience varying degrees of disruption. We have not accounted for how surviving industrial facilities might face progressive degradation over time as replacement parts become unavailable. Additionally, we have not explored recovery dynamics.

Future work should examine industrial adaptation potential in post-nuclear scenarios. The COVID-19 pandemic demonstrated capacity for industrial conversion, with cosmetics producers manufacturing hand sanitizer and car manufacturers building ventilators (*59*). Similar strategies have been proposed for global food catastrophes, such as converting paper mills and breweries to produce lignocellulosic sugar for human consumption (*60*). Likewise, biofuel and biomass-based solutions could provide alternative energy sources if the conventional energy infrastructure is disabled (*61*–*63*).

Integrating GCIL impacts with existing nuclear winter impact models (*8*) would provide a more comprehensive assessment of post-nuclear war food security challenges. Our analysis of supply chain cascade effects through historical analogues could also help assess other GCIL scenarios, such as extreme pandemics where widespread absenteeism disrupts industrial operations, coordinated cyberattacks on critical infrastructure, or severe space weather events (*11*, *24*).

Materials and Methods

Industrial infrastructure data and analysis

We used OpenStreetMap (OSM) data to identify industrial assets. We extracted polygons tagged with landuse=industrial, which encompasses factories, warehouses, and other land designated for industrial purposes. For each simulated detonation, we calculated the overlap between its destruction radius (as determined by our yield scaling relationship) and these industrial polygons.

To estimate the fraction of a country's industrial capital lost in a given scenario, we computed the ratio of destroyed industrial polygon area to total industrial polygon area within that country. While this area-based weighting approach has limitations in capturing variations in industrial output density, it provides a reasonable first-order approximation, supported by the strong correlation between industrial land area and economic output observed in regional analyses (*64*). However, manual inspection revealed that the largest polygons with areas surpassing 10 km² typically represent low-capital facilities like quarries and proving grounds. To avoid overweighting these outliers, we ignored industrial areas larger than 10 km².

To validate OSM data completeness, we conducted a quality assessment focusing on oil refineries and fertilizer/pesticide manufacturing facilities in the United States, India, and Pakistan. We compiled reference datasets of 157 oil refineries (127 in US, 23 in India, 7 in Pakistan) and 65 fertilizer/pesticide facilities (37 in US, 25 in India, 3 in Pakistan). Of these facilities, 99% of refineries and 95% of fertilizer/pesticide plants were correctly tagged as industrial zones in OSM data.

Our analysis was implemented in Python using geospatial libraries (*65*) to process industrial infrastructure data and calculate destruction patterns. The code processes lists of detonation coordinates and yields and calculates the resulting industrial destruction for each target location based on the burn radius scaling derived previously.

Historical case studies analysis

To estimate how direct infrastructure losses propagate through supply chains to affect total industrial output, we analyzed nine historical events and economic models where both the fraction of industrial infrastructure disabled and the resulting decline in industrial production could be estimated:

- 2005 Hurricane Katrina: In 2004, Louisiana and Mississippi respectively accounted for 1.1% and 0.2% of total US industrial activity (*66*). To estimate the fraction of industrial infrastructure disabled by the hurricane, we use housing damage as a proxy: 19% of Louisiana's housing stock and 11% of Mississippi's were destroyed or severely damaged (*67*), suggesting similar levels of industrial infrastructure damage. Weighting these destruction rates by each state's share of national industrial GDP yields approximately 0.23% loss of US industrial infrastructure. This disruption is estimated to have reduced total US industrial production by 1.7% in September 2005 (*68*), the month following Katrina's landfall.
- 2011 Thailand floods: Severe monsoon flooding inundated a large fraction of Thailand, including seven major industrial parks. A World Bank report provides damage assessment data for five provinces that collectively contained 41% of the nation's industrial base (*69*). These provinces, which accounted for 70% of industrial activity among all flood-affected areas, experienced an average of 60% damage to their facilities. Based on these figures, and accounting for damage in other affected provinces, we estimate total national industrial losses of approximately 35% (41% x 60% / 70%). Given that Thailand represents 1.1% of the world's real industrial GDP (*40*), we estimated that 0.38% of global industrial infrastructure was disabled. This disruption is estimated to have temporarily reduced world industrial production by 2.5% (*70*, *71*), largely due to interruptions in global electronics and automotive supply chains.
- Present-day Korean war model: We considered a simulated scenario of a North Korea-South Korea war that leads to a 40% reduction in South Korean manufacturing capacity (*72*). Given that South Korea represents 1.8% of global industrial real GDP, this corresponds to a loss of approximately 0.7% of worldwide industrial infrastructure. The analysis estimates this would reduce global GDP by 3.9% (*72*). Converting this GDP impact into industrial output terms yields two bounds. First, assuming the GDP reduction stems entirely from industrial disruption and given that industry represents 30% of global GDP, this implies a 13% reduction in industrial output. If instead the GDP impact is evenly distributed across sectors, this implies a 3.9% industrial reduction. We considered the midpoint of 8.5% in Fig. 3.
- 2011 Tōhoku earthquake: 405,000 buildings were completely destroyed or severely damaged following the earthquake (*73*). Assuming the vast majority of buildings are residential, this corresponds to 0.8% of all buildings in Japan (*74*). Taking this percentage as a proxy for destroyed industrial capital, we estimate that 0.8% of Japan's industrial base was lost. The disaster caused national industrial production to fall by 15% (*41*).
- 2022 Russian invasion of Ukraine: Russia's invasion led to destruction of Ukrainian industrial facilities. Excluding the agricultural and service sectors, Ukraine lost approximately 3.5% of its productive infrastructure in 2022 (*75*). Industrial production fell by 37% that same year (*76*)
- 1974 US nuclear war study: A 1974 study of the consequences of nuclear attacks on US industry concluded that a 10% loss in the production capacity of basic sectors would reduce the output of defense-related industries by 30-40% (*77*).
- WWII bombing of Germany: By the end of World War II, Allied bombing had destroyed 17% of German industrial capital (*47*). The British Bombing Survey Unit found a 48% loss

in overall armaments production, 59% in aircraft production, and 42% in tank production in 1945 (*48*). Taking these figures as representative, we estimated a 50% reduction in total industrial output.

- WWII bombing of Japan: US bombing during World War II destroyed 34% of Japan's industrial machinery and equipment (*49*). In 1946, industrial production had fallen by 72% compared to prewar levels (*50*).
- 1950-1953 bombing of North Korea: During the Korean War, US bombing destroyed approximately 70% of North Korea's industrial infrastructure, and almost all of the surviving industry was not in operation (*78*). We assumed a 95% production decline to match this qualitative assessment.

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