The Next 50 Years: Fatal Discontinuities

Vaclav Smil

Any one of us may indulge in speculations about global futures tailored to particular moods or biases, from Francis Fukuyama's (1992) ahistorical end of history (to be delivered by the universal triumph of liberal democracy) to Paul Ehrlich's latest lament that sees the very same liberal democracy soon to be one with Nineveh (Ehrlich and Ehrlich 2004).[1] This never-ending parade of grand forecasts has one thing in common: their outcomes are preconceived, and their arguments are predetermined by strongly held visions, be they of inexorable progress or unavoidable collapse. And then there is a burgeoning field of specific point forecasts, supposedly the outcomes of disinterested exploration, that quantify numerous attributes of populations, environments, techniques, or economies. The internet has made it a matter of seconds to find the requisite data for particular years: total number of females in Yemen in 2040, CO_2 concentrations in the atmosphere in 2030, share of electricity generated by wind turbines in Denmark in 2020, the aggregate US national debt in 2010.

The only sensible way to appraise the reliability of such forecasts is to look back and see how well their counterparts foretold yesterday's and today's realities. Such backward-looking exercises are particularly valid because during the past generation most of these specific point forecasts have relied on the same suite of intellectual approaches and (often computerized) forecasting techniques as do today's prognoses that look five to 50 or more years ahead. These retrospectives reveal that most of the truly long-range quantitative forecasts (spanning roughly one generation, or between 15 and 25 years) turn out to be useless within years, even within months, of their publication. I have demonstrated these failures by a detailed examination of more than a century of every possible category of long-range energy forecasts (Smil 2003).

Trend forecasts fail so rapidly because they tend to be unrealistically static. But trends are not infinite: they weaken or deepen suddenly, they can be reversed abruptly. Population forecasts provide pertinent examples of these repeatedly failed anticipations. The unprecedented decline of Russia's fertility was obviously taken into account when the medium variant of the 1998 revision of the UN *World Population Forecast* put the country's total at 121.25 million people in the year 2050 (United Nations 1999); but that trend had deepened so rapidly that a mere four years later the 2002 revision offered only 101.45 million (United Nations 2003), and then it weakened a bit so the 2004 revision raised Russia's 2050 population total to 111.8 million (United Nations 2005). In this single instance these rapidly obsolete forecasts first lost 20 million and then found 10 million people within just six years.

Failed forecasts can also bring good news. For example, an unexpectedly rapid decline of Iran's total fertility rate (it fell from more than 6.5 during the early 1980s, the first years after the fundamentalist mullahs overthrew the Pahlavi dynasty, to about 2.5 by the late 1990s) forced the UN forecasters to lower the country's 2050 level to 1.85, that is, well below replacement. And a comparison of the 2004 revision with the UN's 1990 forecast (United Nations 1991) that ended in the year 2025 shows the difference of about 600 million people, the reduction about 10 percent greater than today's entire population of Latin America. Thus, even forecasts that deal with given biophysical realities (most of the females who will give birth during the next 20 years are already alive) and that are issued only a dozen years apart can differ by continent-size margins. I have no desire to add to this almost instantly irrelevant mountain of specific point forecasts.

Nor do I want to become an inventive fabulist and proffer assorted scenarios, a practice that is now so popular among think tanks, long-term strategy departments of major corporations, and consultants of every stripe.[2] Although a few of these tales make interesting reading, most of them are memorable because of their catchy titles (Civilizations Collide; Uneasy Peace; Biotech Bonanza) rather than because of their content. The principal reason why even the cleverest and the most elaborate explorative scenarios are ultimately so disappointing is that they may get some components of future realities approximately right, but they will inevitably miss other ingredients whose dynamic interaction will create profoundly altered outcomes.

Suppose that in 1975 (years before the adoption of the one-child policy) a group of scenario writers correctly forecast China's population total in 2005. It is a safe conclusion that no group, however learned and imaginative, would have set that number (during the last phase of the Maoist Cultural Revolution) in the context of a more than quadrupled quasi-capitalist economy that is absorbing tens of billions of dollars of direct foreign investment annually, is now the prime workshop for the world, and is the second largest buyer of US government debt.

I offer no quantitative point forecasts, then, no alternative scenarios: instead, my intent is to explore those key variables (whether physical, social, or economic) whose impact is likely to be large enough to shape the course of world history during the next 50 years. My firm belief is that looking far ahead is done most profitably by looking far back. Naturally, there are no specifics to be learned from such an exercise, yet those extended retrospectives impress with one key lesson: history advances as much by saltations—sudden discontinuities—as it does by a gradual unfolding of long-lasting trends. In this respect history mirrors, in a much contracted fashion, the record of life's evolution on Earth that is marked both by very slow (Darwinian) transformations and by relatively sudden (discontinuous) changes (Simpson 1983; Eldredge and Gould 1972).[3] As just explained, the increasingly frequent attempts at long-range projections (ranging from dynamic modeling to scenario building) are of a gradualistic variety, resting largely on following and embellishing a number of critical trends.

A later essay will examine a number of these gradual, evolutionary processes that may profoundly influence the size of human populations and the basic contours of modern history. Its main topics will include the new population realities (resulting mainly from differential growth, regional redistributions, aging, and migration), socioeconomic trends with capacity for long-lasting global impacts (marginalization of Japan, Islam's role, Russia's possible reemergence as a major power, China's rise and its checks), changing global leadership (resulting from America's likely retreat), and worrisome environmental trends (dominated by relatively rapid global warming and the unprecedented loss of biodiversity). Here I focus on those unpredictable discontinuites whose consequences—in terms of lives lost and disrupted, economies destroyed and transformed, outlooks dashed and altered—could change humanity's collective fortunes during the next 50 years.

Fatal discontinuities

These events fall into three broad categories.[4] In the first one are known catastrophic risks, events whose probabilities could be assessed in meaningful ways given the reasonably well-known biophysical realities and historical precedents. Both their near- and long-term recurrence can be quantified in a revealing, in some cases even satisfactory (though always imperfect), manner. This category includes such disparate events as the Earth's encounters with large extraterrestrial bodies and extraordinarily virulent pandemics.

In the second category are the events that have never taken place, whose likelihood thus eludes any meaningful quantitative assessments both as concerns their occurrence (some have been widely anticipated for decades) and their impact but that should not be excluded from the assessment of future fatal discontinuities. Who can quantify the chances of an accidental nuclear war or (a more recent worry) the probability of Pakistan's nuclear arsenal ending up in the hands of jihadis? And who can then estimate the casualties of a launched missile and of a devastating retaliation?

The third category includes entirely speculative events as well as the risks that remain completely unknown. A clear example of the former is Bill Joy's vision of new omnivorous "bacteria" capable of reducing the biosphere to dust in a matter of days (Joy 2000). Obviously, no one can give examples of the latter, but the likelihood of such unknowable surprises increases as the time span under consideration lengthens.[5] Still it is worthwhile to comment on key speculative unquantifiable risks and assign them to two basic categories of more and less worrisome events: this division can be based on the best relative ranking of (guess)timated probabilities, on the most likely overall impact of such developments, or, best of all, on the combination of these two factors.

First the discontinuities whose very occurrence remains purely speculative and that, as many critics would argue, should be more appropriately relegated to the realm of science fiction. The rationale for addressing these matters was aptly described in Tom Wolfe's (1968) bemused description of the way America's business leaders of the late 1960s reacted to the quasi-prophetic (and often utterly incomprehensible) statements of Marshall McLuhan: what if he is right? Several of these highly speculative concerns were widely popularized by Bill Joy's (2000) lengthy paper about the danger of three powerful twenty-first century techniques—robotics, genetic engineering, and nanotechnology—that are threatening (fairly imminently?) to make humanity redundant or outright extinct.

Joy's overblown, curiously self-absorbed, and poorly conceived piece was largely a derivative effort based on the work of two artificial intelligence enthusiasts, Hans Moravec (1999) and Ray Kurzweil (1999), who maintain that robotic intelligence will soon rival human capability. Joy's most sensational claim was reserved for the aforementioned claim about new omnivorous microbes that could swiftly dispose of the entire biosphere. Joy might have been less agitated had he acknowledged some fundamental ecological realities and considered the necessary resource and interspecific competition checks on such a runaway scenario: microorganisms have been around for some 3.5 billion years and evolutionary biologists have difficulty envisaging a new one that could do away, almost instantaneously, with all other organisms that have survived, adapted, and prospered against such cosmic odds.[6]

As for the armies of superintelligent, omnipotent robots, we have been promised their advent for several generations (Čapek 1921; Hatfield 1928). There are no such machines today; even the most "intelligent" software installed in IBM's Deep Blue II in order to beat Garry Kasparov in 1998 did not show the coming triumph of machines but merely, as John Casti (2004:680) noted, that "world-class chess-playing can be done in ways completely alien to the way in which human grandmasters do it." And while computers have been used for many years to write software and to assemble other computers and numerous machines, such deployments do not indicate any imminent self-design and self-assembly capability, as all of those processes require human actions to initiate them, raw materials to build the hardware, and, above all, energy to run them. I find it hard to visualize how those machines (particularly in less than a generation) would launch, integrate, and sustain the exploration, extraction, conversion, and delivery of the requisite multitude of energies.

In any case, there is little we can do about the frightening (or liberating: no human worries anymore) events in Joy–Kurzweil–Moravec visions. If the emergence of superior machines or all-devouring nanospecies is only a matter of time, then we are just passive spectators waiting to be eliminated. If such developments are possible but not certain, we have no rational way to assess the risk: is there a 75 percent or 0.75 percent chance of self-replicating robots taking over by 2025 or of nanobots being in charge of the Earth by 2050? And if such threats are more than pretentious, upscale science fiction, then they have a massive amount of company in print, film, and television and are good for little more than their intellectual frisson effect.

By far the most catastrophic unquantifiable risk is the possibility of accidental nuclear war, a fear that has been with us since 1951.[7] During the height of the Cold War, casualties of an all-out thermonuclear exchange between the two superpowers (including its aftermath) were estimated to reach hundreds of millions (Coale 1985), and on several occasions we came perilously close to such a civilization-terminating event. Nearly four decades of the superpower nuclear standoff were punctuated by a significant number of accidents that involved nuclear submarines and long-range bombers carrying nuclear weapons, and by hundreds of false alarms caused by malfunctions of communication links, by errors of computerized control systems, and by misinterpretation of remotely sensed evidence. Many of these incidents have been detailed after a lapse of time in Western publications (Sagan 1993; Britten 1983; Calder 1979), and there is no doubt that the Soviets have had a similar (and likely even larger) number of such momentarily terrifying experiences. Probabilities of such mishaps escalating out of control rose considerably during the periods of heightened crises, when a false alarm was much more likely to be misinterpreted as the beginning of a thermonuclear attack.

A series of such incidents took place during the most dangerous moment of the Cold War, the October 1962 Cuban Missile Crisis (Blight and Welch 1989; Allison and Zelikow 1999). On 24 October a Soviet satellite exploded shortly after reaching its orbiting height; on 25 October a sabotage alarm triggered by a bear led to the takeoff of nuclear-armed F-106A interceptors; on 26 October a US U2 spy plane strayed into Soviet airspace above Chukotka; on 28 October a New Jersey radar station mistook a satellite pass for a missile launch as did a newly activated radar site in Laredo, Texas. The outcome of all of these incidents is well known: there was never any accidental launch, either attributable to hardware failure or to misinterpreted evidence. One of the architects of the (in retrospect remarkably stable) Cold War regime in the United States concluded that the risk was small because of the prudence and unchallenged control of the leaders of the two countries (Bundy 1988).

How small depends entirely on the assumptions made in order to calculate cumulative probabilities of avoiding a series of catastrophic mishaps. Even if the probability of an accidental launch were just 1 percent in each of some 20 known US incidents (i.e., the chance of avoiding a catastrophe being 99 percent), the cumulative likelihood of avoiding an accidental nuclear war would be about 82 percent, or, as Philips (1998: 8) rightly concluded, "about the same as the chance of surviving a single pull of the trigger at Russian roulette played with a 6 shooter." But these are meaningless calculations. As long as the time available to verify the real nature of an incident is shorter than the minimum time needed for a retaliatory strike, the latter course can be avoided and the incident cannot be assigned any definite avoidance probability: if the evidence is initially interpreted as an attack underway but a few minutes later this is entirely discounted, then in the minds of decisionmakers the probability of avoiding a thermonuclear war went from zero to 100 percent within a brief span of time.[8]

The demise of the Soviet Union undoubtedly diminished the chances of accidental nuclear war thanks to a drastic reduction of total warheads deployed by Russia and the United States: in January 2005 Russia had some 7,200 warheads compared to its peak total of 45,000 in 1986, and the United States had about 5,300 warheads compared to its peak of 32,500 in 1967. Further cuts lie ahead: the Strategic Offensive Reductions Treaty signed in May 2002 will reduce total warheads to fewer than 2,200 on either side by the year 2012 (Norris and Kristensen 2005a and 2005b). But Forrow et al. (1998) argued that because of the aging of Russian weapons systems, the risk of an accidental nuclear attack had actually increased. They also calculated that an intermediate-sized launch of warheads from a single Russian submarine would kill nearly instantly about 6.8 million people in eight US cities and expose millions more to potentially lethal radiation.

Moreover, with more countries possessing nuclear weapons, it is possible to argue that chances of accidental launching and near-certain retaliation have been increasing steadily: since 1945 an additional nation has acquired nuclear weapons roughly every five years, North Korea being the latest entry and Iran the next most likely candidate. The North Korean case introduces another dimension of the unknown since we cannot be certain whether we are dealing, as many facts indicate, merely with an exceedingly devious leadership that is engaged in a risky game of serial extortion or with men who are willing to pull down their peninsular temple on their own heads as they launch a suicidal attack on the United States (Albright and O'Neill 2000; Cha and Kang 2003).

Terrorism has been a recurrent form of unconventional warfare in the modern world, and murder by suicide has deep roots in Muslim history (Andriolo 2002), but only the attacks of September 11, 2001 elevated this kind of violence to the class of catastrophic events whose recurrence could profoundly change history. In the wake of that attack, modalities and consequences of possible future terrorist actions have been explored—at once excessively yet insufficiently, with exaggeration as well as with inadequate appreciation of possibilities—but their probability remains beyond any useful quantification. Their list ranges from launching cyber attacks on modern electronic infrastructures and poisoning of urban water or food supplies to the decapitation of a national leadership and, of course, explosion of a dirty bomb and releases of old or new pathogens. Public policies and precautionary actions dictate that none of these incidents, no matter how low its probability might seem, can be simply dismissed as too unlikely. But this very reality makes it highly difficult to manage the challenge because we are unable to assess the relative likelihood of many different modes of attack.

A skeptical appraisal must point out at least two facts: many of these attacks are not as easy to launch as the sensationalizing media coverage would lead us to believe, and many of them, even if successfully executed, would have relatively limited consequences and would not rise to the level of developments capable of transforming history.[9] This is particularly true about the attacks that Homer-Dixon (2002) defined as ingredients of complex terrorism: actions that are much easier to launch than spectacular mass murders but that might prove ultimately both costlier and deadlier. Terrorists would exploit growing complexities of modern societies and deploy their "weapons of mass disruption" by attacking nonredundant nodes of critical infrastructures, be they electricity networks, other energy supply systems, chemical factories, or communication links.

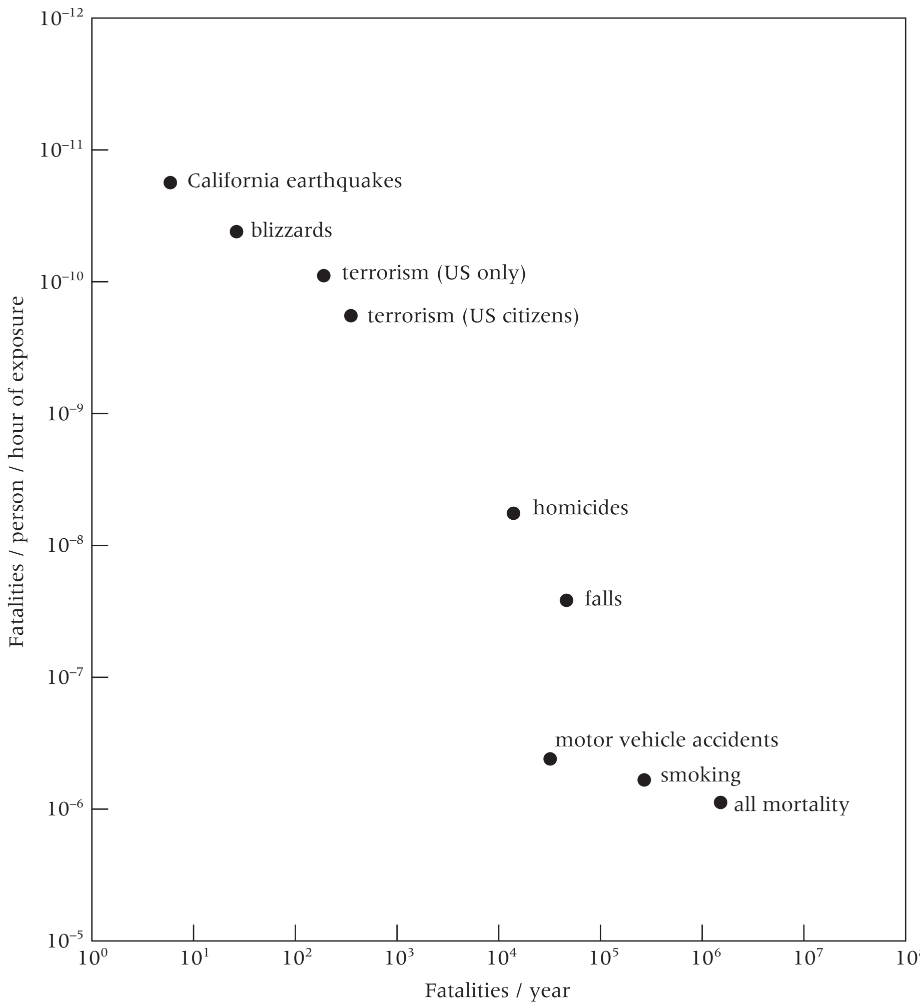
A skeptical riposte to this scenario is to ask, given that many of these attacks are so trivially easy to launch, why we are not seeing scores of them every month. After all, it is impossible to safeguard against explosives every one of hundreds of thousands of steel towers that carry a large nation's high-voltage lines, or to protect round-the-clock every one of tens of thousands of transforming substations (or, facing a different threat, to detect every poisoned kilogram among millions of tonnes of harvested crops or to secure thousands of reservoirs and river water intakes that furnish drinking water). A relatively rich experience with accidental large-scale electricity supply outages (caused by weather, human error, or a technical problem) demonstrates that similar, or even larger, failures would not rise to the level of historic milestones.[10] Indeed, the use of weapons of mass disruption would be most likely to amount to a spatially and temporarily limited (albeit possibly fairly expensive) disruption, remaining far below the threshold of events capable to appreciably modify the course of global history.

Those who argue that a greater complexity generates increased vulnerability should also keep in mind that it also brings greater resilience. Evolution of complex life is based on this very principle: otherwise the terrestrial biosphere would consist just of simple bacterial mats that would preclude the emergence and complexification of climactic grasslands and forests. And the success of our species makes it clear that humans, unlike all other organisms, have evolved not to adapt to specific conditions and tasks but to cope with change (Potts 2001). This ability makes us uniquely fit to cope with assorted crises and to transform many events from potentially crippling milestones to resolved challenges. This capacity would be most severely tested by a nuclear war, whether through a failure of national controls, a madly deliberate launch by an irrational leadership, or a takeover of nuclear weapons by a terrorist group: the unknown risk of this catastrophe may be very low but no other anthropogenic act comes close to causing as many instant casualties.

Threats from the weapons of mass disruption (including any truly dangerous deployment of pathogens) would rank much lower than a nuclear holocaust, and I would relegate the prospects of life crippled by entirely new pathogens and devoured by nanobots for science fiction accounts. Early-twenty-first-century societies will have to live with all of these unquantifiable threats, and the risk of terrorist attacks will be particularly prominent owing to media attention and the nature of the American political process. But we would be much better off if we were to treat this threat with broad statistical risk assessments in mind. Even if unavoidable, many of these attacks represent much lower dangers (be it from an individual's or a collective's perspective) and have less profound and long-lasting consequences from the standpoint of national stability, economic damage, and standard of living than do a number of voluntary risk exposures (drinking, driving, smoking, overeating) and deliberate yet deleterious policy actions (ranging from enormous budget and trade deficits to subsidies and unchecked environmental destruction).

Indeed, Chapman and Harris (2002) argued that the disproportionate reaction to the attacks of 9/11 was as damaging as the direct destruction of lives and property. Relative risks are best shown in terms of fatalities per person per hour of exposure, a risk assessment approach that was originally developed by Chauncey Starr (1969). I have used it to calculate a number of relevant US rates for a 15-year period between 1989 and 2004. Their plot in Figure 1 shows the risk of dying because of terrorism in the United States (including all 1993 and 2001 World Trade Center fatalities and the

FIGURE 1 US fatalities per person per hour of exposure plotted against the average annual number of fatalities during the 15 years between 1989 and 2004 (both axes are logarithmic)



SOURCES: Calculated from data in CDC (2005) and from a variety of reports on natural catastrophes and terrorist activity.

1995 fatalities from the Oklahoma bombing) to be only slightly higher than the risk of dying in a blizzard somewhere in the country. When the deaths of all US citizens attributable to terrorism are included—those from 1996 Saudi Khobar Towers and 1998 East African embassies bombing, from the Yemeni attack on the *USS Cole* and even from combat in Afghanistan and Iraq—the rate about doubles to $2\text{x}10^{-10}$, still an order of magnitude below the annual risk of homicide and three orders of magnitude below the annual risk of fatal car accidents.

During the first five years of the twenty-first century the US highway death toll exceeded the 9/11 fatalities every single month; at times it was higher in just three weeks. And even one of the worst cases from recently leaked terrorist attack scenarios prepared by the Department of Homeland Security (Jakes 2005) does not imply an extreme risk. Spraying of anthrax from a truck driving through five cities over two weeks was estimated to kill 13,200 people; if these actions were to take place in metropolitan areas with populations of at least 2 million people each and be repeated every ten years, then even such an unlikely recurrence (and high fatality assumptions) would prorate to only 1.5×10^{-8} fatalities per person per hour of exposure, a risk lower than the risk of dying from an accidental fall and less than 1/30 of the risk due to driving. Many more deaths could be prevented while spending much less per life saved by investing in extreme weather education, safer stairways, and enforcement of lower speed limits and no-drinking-and-driving laws. But disproportionate reactions to fatalities arising from rare, involuntary, and spectacular risks will not be changed easily.

The rest of this essay is devoted to those unpredictable discontinuities whose comparative probabilities can be quantified with a degree of accuracy that is useful for assessing relative risks and allocating resources for preventive actions or for eventual mitigation. Three kinds of such events fulfill the combined requirement of an extraordinary magnitude, global impact, and long-term consequences: natural catastrophes, pandemic illness, and transformational wars. I will look only at those natural catastrophes that do not have a vanishingly low probability during the coming 50 years, that is, those that recur with intervals no longer than 100,000 years and that could shape world history because of their directly lethal effects or the long-term changes they might inflict on the biosphere.

This is why I leave aside such very rare events as the Earth's exposure to supernova explosions, its head-on collisions with massive comets (which are much less common than encounters with nearby asteroids), or periods of enormous lava flows (such as those that created India's Deccan Traps by piling up about one million km^3 of basaltic lavas over a period of about 5 million years beginning some 65 million years ago). And because neither an abrupt climate change nor an altered intensity of ocean circulation (two events that have been commonly posited as potentially major environmental crises of the coming decades) can unfold as rapidly as the natural discontinuities examined in this essay, I will deal with them in the aforementioned subsequent essay on globally important changing trends.

Natural catastrophes

Recurrent natural catastrophes can claim hundreds of thousands, even millions, of lives per event. The most recent case in this category, the December 2004 Indian Ocean tsunami, was a convincing illustration of the fact that while these catastrophes may elicit worldwide humanitarian response, they do not alter the course of world history.[11] Indeed, one of half a dozen similarly devastating events that took place during the latter half of the twentieth century remained an entirely internal affair as xenophobic China, just seven weeks before Mao Zedong's death, did not ask for international help following the Tangshan earthquake of July 1976 that killed, officially, 242,219 people in that coal-mining city and in its surroundings but whose toll was estimated to have been as high as 655,000 (Huixian et al. 2002; Chen et al. 1988).

In contrast to frequent natural disasters, there are only three kinds of sudden, unpredictable, but recurrent natural events whose global, hemispheric, or large-scale regional impacts can have profound influence on the course of history: the Earth's collisions with nearby extraterrestrial objects, massive volcanic eruptions (some also generating major tsunami), and (possibly) voluminous, tsunami-generating slides of parts of volcanoes into the ocean. The probability of any of these events is very low during the coming 50 years, but this comforting appraisal must be counterbalanced by the fact that if any one of them were to take place it would be an event without counterpart in recorded history: the near-instant death toll would reach 1 million to 10 million people, one to two orders of magnitude higher than for high-frequency natural catastrophes.

The Earth constantly passes through highly dispersed (but in aggregate quite massive) amounts of cosmic debris whose most common sizes range from microscopic particles to meteoroids with diameters of less than one meter. This constant infall poses virtually no risk to life, but the planet is also periodically hit by much larger objects whose size and energy determine the consequences of such impacts. Hills and Goda (1993) calculated that stone objects with diameters of up to about 150 m will release most of their energy in the atmosphere and will not hit the surface and create impact craters. Bland and Artemieva (2003) increased the size of objects that produce only air blast to 220 m in diameter. Larger objects (and also heavier, but much rarer, iron-nickel bodies) will strike the surface, but the odds are roughly 7:3 that they will hit the ocean and will damage the land only indirectly by generating tsunami.

The destructive radius of ground impacts and the amount of debris lifted into the atmosphere would be the function of the size and speed of the incoming objects. Very large bodies (at least one km in diameter) would produce longer-term global climate change regardless of the point of their impact. Recent research has produced more reliable accounts of the numbers of near-Earth objects and of the probabilities of their collision with the Earth. Rabinowitz et al. (2000) used improved detection techniques to conclude that there are nearly 1,000 near-Earth objects with diameters in excess of one km, about half the total of earlier estimates. Stuart (2001) narrowed the total number of kilometer-sized near-Earth asteroids to just over 1,200 and also found them less likely to collide with the Earth.

Brown et al. (2002) used the US Department of Defense and Department of Energy satellite designed to detect nuclear explosions in order to identify light records of detonations of objects in the 1 to 10 m size range in the atmosphere. From these observations they concluded that, on average, the Earth is struck by an object with energy equivalent to 10 Mt TNT (about 50 m in diameter) every 1,000 years, about five times less frequently than thought only 20 years ago (uncertainties widen the frequency range to between 400 and 1,800 years). The probability of such an impact is thus about 5 percent (2.8–12.5 percent) during the next 50 years, and its effect would be similar to that caused by the famous Tunguska meteor of 1908, a stony object that disintegrated in the atmosphere, produced a shock wave that flattened trees over an area of about 2,150 km^2, but killed nobody (Dolgov 1984).

A similar object, were it to disintegrate over a densely populated urban area, could cause great damage: after all, its explosion (at about 15 km above ground) would release energy equivalent to 100 or so Hiroshima bombs and the resulting blast wave would destroy many structures and kill many thousands of people.[12] But the chances of such an event are roughly two orders of magnitude smaller than the probability of its hitting an unpopulated or thinly-inhabited region; and, as was clearly demonstrated by the contrast of casualties in Hiroshima and Nagasaki, the actual destruction would depend on the physical configuration of the affected area.[13] The Earth is also hit roughly once a year with an extraterrestrial body whose airburst is equivalent to 5 kt TNT, about a third as powerful as the Hiroshima bomb, and if this body's center of disintegration were right above the US Capitol during the President's State of the Union address the effect would be felt globally. But the probability of such an encounter is vanishingly small, at least eight orders of magnitude smaller than that of a similar object disintegrating any time above any densely populated area.

Impacts of global consequence would be produced only by asteroids with diameters of at least one km and by much rarer comets whose return orbits cannot be reliably calculated long in advance and whose threat is only about 1 percent of that of near-Earth objects. The good news is that the assumed probability of their near-term impacts has been decreasing: by 2003 the international telescopic Spaceguard Survey had already identified about 55 percent of all such objects with a diameter in excess of one km, and it found that none of them is on a trajectory that would lead to its collision with the Earth during the twenty-first century (NEOSDT 2003). Once the survey is complete (by the end of 2008) the residual hazard (averaged over a very long period of time) might be only on the order of 100 annual fatalities worldwide (that is, causing 100,000 fatalities once every

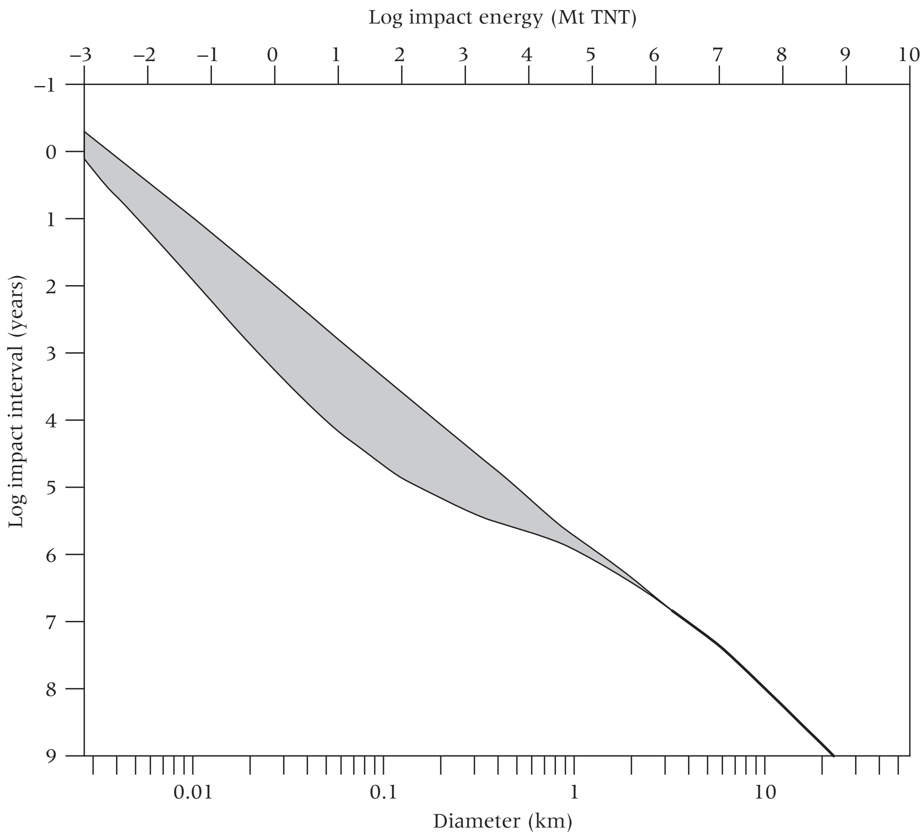
1,000 years). The greatest land-impact hazard will come from smaller bodies (with more than a 1 percent chance that such an impact will kill about 100,000 people during the twenty-first century) while somewhat larger bodies (150 to 600 m in diameter) will pose the greatest tsunami hazards (Chapman 2004).

The general size-frequency distribution of near-Earth objects is now fairly well known (Figure 2), but, not surprisingly, there are different assumptions regarding the most likely frequency of impacts. Ward and Asphaug (2000) assume that an object with a diameter of 400 m hits the Earth once every 10,000 years and that a one-km body hits once every 100,000 years. In contrast, Brown et al. (2002) would expect a 400-m body every 100,000 years and a one-km object every 2 million years; Chapman (2004) would have the 400-m body hit once in a million years; and Jewitt (2000) opted for 400,000 years. If an asteroid with the diameter of 400 m were to hit the ocean at 20 km/second, the maximum amplitude of a tsunami generated by this impact would be about 50 m at the distance of 100 km (and nearly 250 m only 20 km away): a near-shore impact offshore California or off eastern Honshū would thus instantly devastate a core region of one of the world's two leading economies and, unlike with tsunami generated by a distant earthquake, it would not give sufficient time for mass evacuation of affected regions.

Global probabilities of an impact of this magnitude are, depending on the recurrence interval, 0.05 to 0.5 percent, and Ward and Asphaug (2000) calculated specific probabilities of a 5-m tsunami wave hitting Tokyo and New York at, respectively, 4.2 percent and 2.1 percent during the next 1,000 years, or roughly 0.2 percent and 0.1 percent during the next 50 years. In contrast, Bland and Artemieva (2003) estimate the frequencies of bolides that would be most likely to cause hazardous tsunamis at only about 1/50 of the rate calculated by Ward and Asphaug. Chesley and Ward (quoted in NEOSDT 2003) concluded that the highest risk of tsunami-generated fatalities comes from smaller but more frequent impacts of objects with diameters of 200 to 400 m and calculated the overall long-term casualties at fewer than 200 deaths a year (or fewer than 10,000 during the next half century).

The impact energy of a one-km body would be equivalent to the release of close to 100 Gt TNT, nearly an order of magnitude more of energy than would have been expended by an all-out thermonuclear war between the two superpowers in 1980 (Sakharov 1983). If its average recurrence interval were 400,000 years, then the probability of an impact during the next 50 years would be 0.0125 percent (with available data justifying an unhelpfully wide range of 0.002 to 0.05 percent). If it were to enter the ocean, such an impact would obviously generate tsunami that would hit even distant shores with high-amplitude waves, and the principal global effect with a continental impact would be due to an immense mass of shat-

FIGURE 2 Size and frequency distribution of near-Earth asteroids (all three axes are logarithmic). Band in the left half of the figure indicates the range of uncertainty regarding the numbers and impact intervals of objects with diameters less than one km.



SOURCE: Based on a graph in NEOSDT (2003).

tered material that would be lifted high into the atmosphere, resulting in a drastic drop of temperature, extensive deposits of dust, and long-term reduction of plant productivity.

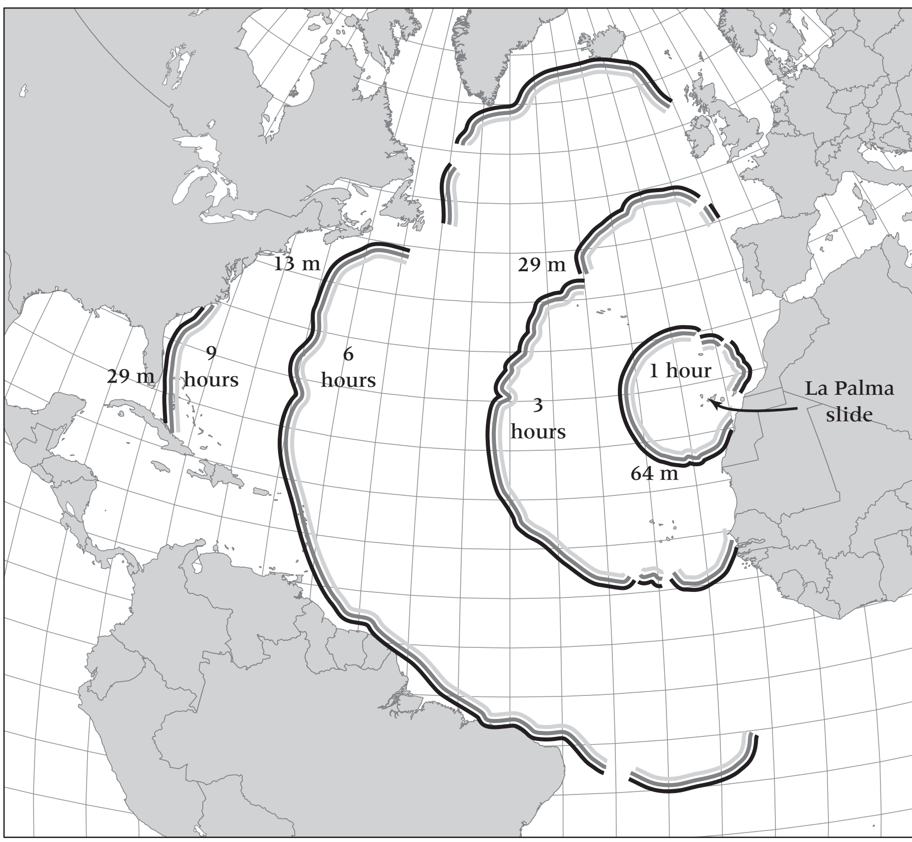
Unusually large volcanic eruptions are the only other category of natural phenomena whose frequencies and global effects are similar to those of major impacts of extraterrestrial objects. The largest one during the Quaternary period was the megaeruption that created the giant Toba caldera (an oval roughly 30 by 100 km filled by a lake) in northern Sumatra about 75,000 years ago (Rose and Chesner 1990): it produced about 2,800 km^3 of ejecta compared to about one km^3 during the Mount St. Helens eruption in May 1980 (Lipman and Mullineaux 1981). Trillions of metric tons of volcanic ash were deposited thousands of kilometers downwind, and volcanic aerosols that persisted in the stratosphere drastically lowered atmospheric temperatures and plant productivity. This catastrophe is perhaps the best explanation for a genetically well-documented late Pleistocene population bottleneck when small and scattered groups of humans were reduced to a global total of fewer than 10,000 individuals and when our species came very close to ending its evolution (Rampino and Self 1992; Ambrose 1998).[14]

Judging by the timing of two previous Toba events, the probability of a similar eruption is about 0.01 percent during the next 50 years, but for North America a more direct threat is presented by recurrent eruptions of the Yellowstone hotspot (Smith and Braile 1994). Eruptions of this supervolcano left behind nine massive calderas during the last 15 million years; the last one, about 630,000 years ago, produced about 1,000 km^3 of volcanic ash. The frequency of the Yellowstone hotspot eruptions actually increased during the past 2 million years with the last two intervals being about 800,000 and 650,000 years, and so another event during the next 50 years has a probability of about 0.007 percent. If it were to produce as much ash as the last eruption, then it could bury about 2 million km^2 of America's heartland (roughly a quarter of the country's territory, including all of the leading wheat-producing states) under half a meter of ash.[15]

Even a much smaller volcanic event could have enormous consequences if it were to cause a massive collapse of volcanic flanks into a nearby ocean and hence generate an extraordinarily large tsunami. Such huge landslides, recurring roughly once every 100,000 years and creating waves in excess of 100 m, were first documented in the early 1960s in the form of massive hummocks of debris on the seafloor surrounding the Hawaiian Islands (Moore, Normark, and Holcomb 1994). Perhaps the greatest risk of this kind is posed by a future eruption of the Cumbre Vieja volcano at La Palma in the Canary Islands that could cause a catastrophic failure of the mountain's western flank (Ward and Day 2001). The resulting landslide of up to 500 km^3 of volcanic rock would generate a rapidly moving (up to 350 km/h) mega-tsunami that would, even after crossing the Atlantic, hit the eastern coast of North America with repeated walls of water up to 25 m high (Figure 3).

The best evidence regarding the frequency of Canary Islands landslides would indicate intervals of about 70,000 years and hence a probability no higher than 0.07 percent during the next 50 years. But a 500 km^3 landslide is the worst-case scenario that also assumes that the slip would take place instantaneously during a single event and enter the sea at high velocity. Halving the failed mass would reduce the maximum waves to 5 to 10 m; and if, as argued by Wynn and Masson (2004) on the basis of their studies of offshore deposits, each landslide were to be composed of multiple stages of gradual failure, then the average collapsed mass could be as low as 10 to 25 km^3 and it would be much less likely to generate tsunamis that could inflict severe damage to the east coast of North America.

FIGURE 3 An unlikely, but potentially devastating natural catastrophe: a massive collapse of Cumbre Vieja in the Canary Islands would generate a tsunami that would hit the eastern coast of North America with a sequence of waves mostly between 10 and 25 m high. Tsunami progress across the Atlantic would allow for ample warning, and a staged collapse of a volcanic flank would produce much smaller trans-Atlantic waves.



SOURCE: Based on results of a simulation exercise by Ward and Day (2001).

Viral pandemics

Modern hygiene, nationwide and worldwide inoculation, constant monitoring of outbreaks, and emergency vaccinations have either completely eliminated or drastically reduced a number of previously lethal, deeply injurious, or widely discomforting epidemic diseases: alphabetically they include cholera, diphtheria, pertussis, polio, smallpox, tuberculosis, and typhoid.[16] At the same time, new infectious diseases keep emerging: recent decades have seen variant Creutzfeld-Jacob disease (the human form of bovine spongiform encephalopathy commonly known as mad cow disease), cryptosporidiosis, cyclosporiasis, hantavirus pulmonary syndrome, SARS, and, of course, HIV/AIDS (Morens, Folkers, and Fauci 2004). None of these new threats, with the obvious exception of HIV/AIDS, appears capable of changing the course of world history, and AIDS could do so only if new, much more virulent strains were to afflict significant shares of populations outside sub-Saharan Africa.[17]

As far as the unpredictable discontinuities are concerned, only one somatic threat trumps all of this: we remain highly vulnerable to another episode of viral pandemic. High-frequency natural catastrophes have their somatic counterpart in recurrent epidemics of influenza, an acute infection of the respiratory tract caused by type A and B viruses belonging to the family *Orthomyxoviridae*. Influenza epidemics sweep the world annually, mostly during the winter months, but with different intensities. In the United States between 250,000 and 500,000 new cases are reported every year, about 200,000 people are hospitalized, and 20,000 people die (less than 0.01 percent of the US population). Infection rates are by far the highest among young children (10 to 30 percent annually) and in people over 65 years of age (Centers for Disease Control 2000). Influenza pandemics have been caused only by type A viruses when one of their subtypes, different from strains that are already present in humans, suddenly emerges, rapidly diffuses around the world (usually within six months), and afflicts between 30 and 50 percent of people.

The illness, with its characteristic symptoms of fever, headache, cough, debilitation, and pain, is often complicated by bacterial or viral pneumonia. The former can be now treated by antibiotics, but because there is no treatment for the latter it becomes a common cause of death during influenza epidemics. The first fairly well-documented influenza pandemic was in 1580, and six known episodes occurred during the last two centuries (Gust, Hampson, and Lavanchy 2001): in 1830–33 (subtype unknown, originating in Russia), in 1836–37 (subtype unknown, originating possibly in Russia), in 1889–90 (subtypes H2 and H3, originating possibly in Russia), in 1918–19 (subtype H1, Spanish flu, originating simultaneously in Europe and in the United States), in 1957–58 (subtype H2N2, Asian flu, originating in Southeast Asia, total excess mortality of more than 2 million), and in 1968–69 (subtype H3N2, Hong Kong flu, originating in Hong Kong, with excess mortality on the order of one million). The low death rate during the last pandemic is attributable to protection that was conferred on many people by the 1957 infection.

All of the nineteenth-century pandemics, as well as the 1957 and 1968 events, were relatively mild and hence did not make any noticeable upticks in the secular trend of declining mortality. In contrast, the 1918–19 pandemic was by far the largest sudden infectious burden in modern times. Its first wave began in February 1918; by May it had spread throughout most of the United States, Western Europe, north Africa, Japan, and the eastern coast of China; by August it was in Australia, Latin America, and India (Patterson and Pyle 1991). Recent studies of this pandemic include books aimed at a general readership (Davies 1999; Kolata 1999; Barry 2004) as well as at experts (Phillips and Killingray 2003). Scientific advances of the 1980s (polymerase chain reaction, permitting replication of genetic material) made it possible to identify the virus that was initially retrieved from formalin-fixed, paraffin-embedded lung tissue samples and used to sequence fragments of viral RNA (Taubenberger et al. 1997). Perhaps the most interesting finding from these studies is the remarkable uniformity of the pathogen, with strains showing 98.9 to 99.8 percent nucleotide sequence identity (Reid et al. 2003).

Statistical analyses of the best available data confirm a peculiar mortality pattern: in contrast to annual epidemics characterized by a typical U-shaped mortality pattern, the 1918–19 pandemic killed predominantly people between ages 15 and 35 years, and 99 percent of all deaths were among people younger than 65 years (WHO 2005). Many of these deaths were due to viral pneumonia that caused extensive hemorrhaging of the lungs with death taking place within 48 hours. But there is little certainty about the most relevant figure of all, the total global death toll: perhaps the most commonly cited worldwide aggregate has been between 20 million and 40 million, but the latest World Health Organization document refers to "upwards of 40 million people" (WHO 2005) and the highest estimates are between 50 and 100 million. Even the lowest estimate is higher than all military and civilian casualties of World War I (about 15 million); the highest figure would about equal the uncertain grand total of fatalities among the populations of the world's two largest Communist regimes of the twentieth century: Stalinist Russia and Maoist China (White 2003).

During the late 1990s, two decades after the last and relatively mild pandemic, concerns arose over the emergence of new avian viruses transmissible to people. In December 1995 a meeting in Bethesda, Maryland on pandemic influenza heard from one of the world's leading experts that "at this time, there is no evidence for or against the direct spread of avian influenza viruses to humans" (Webster 1997: S18). By the time this presentation was published, the subtype H5N1 had mutated in Hong Kong's poultry markets to a highly pathogenic form (first identified in April 1997) that could kill virtually all infected chickens within two days, and in May 1997 came the first human death (Sims et al. 2002).

The virus was eventually transferred to at least 18 people, causing six deaths and the slaughter of 1.6 million birds (Snacken et al. 1999). This episode showed for the first time that avian influenza viruses could infect humans directly, without passing through pigs or other intermediate hosts. Two years later Hong Kong had two poultry-to-people transfers of subtype H9N2, and starting late in 2003 and during 2004 the highly pathogenic subtype H5N1 began to appear again in poultry in at least eight Asian countries. Eventually more than 200 people were infected with avian viruses (besides H5N1 also H9N2, H7N7, and H7N3) in Hong Kong, Netherlands, Canada, Vietnam, and Thailand with nearly 40 deaths in Vietnam and Thailand combined. The Thai outbreak was particularly widespread, and it required the slaughter of 40 million chickens in 41 provinces (Chotpitayasunondh et al. 2004). Studies showed that domestic ducks in China's southern provinces are the key reservoir of H5N1 viruses (Chen et al. 2004). Because these viruses are highly pathogenic and have become ineradicable throughout parts of Asia, they have a clearly pandemic potential (Li et al. 2004).

Expert consensus may be wrong but it is certainly disconcerting to see that epidemiologists and virologists are in general agreement about a very high probability of pandemic influenza in the not too distant future—if not in a matter of months or years, then likely within the next one or two decades. Optimistic forecasts see 20 percent of the world's population falling ill, one in every 100 ill people requiring hospitalization (provided the beds will be available), and 7 million deaths in a few months (Stöhr and Esveld 2004). But the morbidity rate may actually be 25 to 30 percent, and the World Health Organization believes that a new pandemic may affect 20 to 50 percent of the world's population. Its toll, however, cannot be responsibly predicted because we have no way of knowing the virulence of new infectious strains. What is certain is that the appearance of subtype H5N1 has brought us closer to the next pandemic, and that whatever its actual magnitude we are utterly unprepared for it and for its consequences (WHO 2005).

The following possibilities indicate the imminence and magnitude of the risk. The recurrence interval, calculated simply as the mean time elapsed between the six known influenza pandemics, is about 28 years, with the extremes of six and 53 years. Adding the mean and the highest interval to 1968 gives us the span between 1996 and 2021: we are, probabilistically speaking, very much inside a high-risk zone. Consequently, the likelihood of another influenza pandemic during the next 50 years is virtually 100 percent, but quantifying probabilities of mild, moderate, or severe events remains largely a matter of speculation because we do not known how pathogenic a new virus will be and what age categories it will preferentially attack.

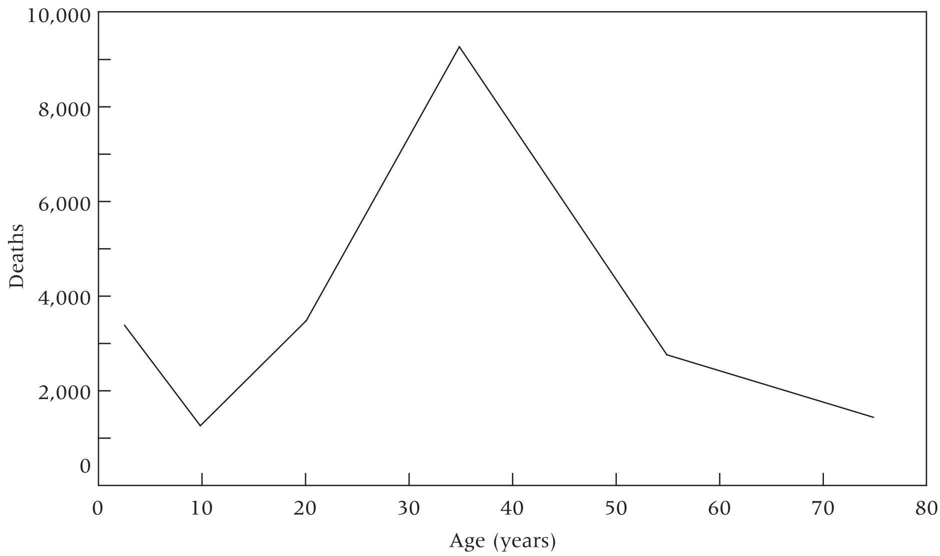
If the eventual death toll were to resemble those of the last two pandemics, with a few million dead, there would be virtually no consequences for the long-term course of world history. If it were a highly similar repeat of the 1918–19 event, with mortality of no less than 20 to 25 million people, the global toll would be relatively only about one-fourth as large as it was four generations ago. But the overall mortality could also be a proportionally potentiated replica of 1918–19: we now have a 3.4 times larger global population, an at least an eight times larger (nearly 20 billion compared to less than 3 billion) inventory of poultry (the main reservoir of lethal viruses, and much of it now in large feeding facilities), and we use an order of magnitude faster means of mass transportation to spread the infections around the world. In 1918 it took six days to cross the Atlantic on an ocean liner; now it takes six hours on a jetliner, and there is no doubt that air travel plays an important role in the diffusion of annual epidemics (Grais et al. 2004).

Even when assuming "only" 25 million deaths in 1918–19, we could see a proportionally increased global mortality surpassing 80 to 100 million people; with 50 million deaths in 1918–19 the proportional total would rise to 150 to 200 million. With a slightly more than 5 percent mortality rate (the well-documented US mean in 1918–19) there could be at least 1.5 to 2 billion very sick people, and it would be clearly beyond the capacity of health services to cope effectively with such a sudden burden. On the other hand, there are positive factors of generally better nutrition, much better hospital care, and incomparably greater virological understanding. The overall enormity of this ubiquitous morbidity and vastly multiplied mortality would pose challenges that have been unseen in most countries of the world for generations: in China since 1961 (the end of massive famine), in Europe (except for some Bosnian villages decimated by mass executions during the 1990s) since 1945, in North America since 1918.

In addition, many specific impacts would complicate our ability to deal with immediate challenges and would have long-term consequences. Detecting a smaller herald wave of infections several months ahead of the main event (as happened in 1918 in the United States) may not be helpful: rather than give us more time to prepare, it may actually cause more helplessness and fear because any development of a new vaccine that would begin only once the pandemic virus started its diffusion could not be completed before the virus would cover the world (Stöhr and Esveld 2004). But the event may not be over in six months, as substantial mortality could continue during the second season, and many cities and countries may find it particularly difficult to cope with such a second wave.

That was certainly the case with Toronto's second wave of SARS in May 2003, minuscule in terms of total numbers but extremely taxing due to mental burdens and logistic problems caused by quarantined hospitals (none but emergency operations, no visits, not even for terminally ill patients). The mortality burden may shift, as it did so stunningly during the 1918–19 pandemic, to younger people: age-specific mortalities in New York showed little or no impact among people aged 45 years and older but an unprecedented spike for younger cohorts (Figure 4). Repetition of this pattern could strain the availability and effectiveness of caregivers (health professionals ranging from physicians to staff at retirement homes) and substantially worsen dependency

FIGURE 4 Age-specific mortality in New York City in October 1918 during the peak of the influenza pandemic shows a W-shaped rather than the common U-shaped (epidemic) profile.



SOURCE: Plotted from data in *Monthly Bulletin of the Department of Health, City of New York* (November 1918).

ratios, particularly in Europe's aging populations where the dependency ratios are already rising to unprecedented levels.

Massive mortality of people in their prime ages would also cause enormous strain on the life insurance industry and it would depress real estate values. And what would 24-hour nonstop news media, so adept at flogging a few accidental deaths to all-day marathons of despair and end-of-the-world comments, do with so many deaths that would just keep coming, day after day, week after week? Can we foresee how the financial markets would react to such massive and indiscriminate dying? More importantly, what would be the long-term economic cost in fear and depression that would come on top of the immediate social and economic insults to the previously insulated Western way of life? To what extent would Europe's ravaged countries become open to unchecked Muslim immigration, speeding up the demise of the continent's centuries-old global influence? What would the resulting cessation of global trade do to the lives of hundreds of millions of factory workers in Asia?

Transformational wars

While trying to assess the probabilities and consequences of recurrent natural catastrophes and catastrophic illness, we must remember that the historical record is unequivocal: these events, even when combined, did not claim as many lives and did not change world history as much as the deliberate kind of fateful discontinuities that Richard Rhodes (1988) calls manmade death, the single largest cause of non-natural mortality in the twentieth century. Violent collective death has been such an omnipresent part of the human condition that its recurrence, on wide-ranging scales of time (conflicts lasting days to decades) and casualties (from individual homicides to democides), is guaranteed. Long lists of past violent events can be inspected in print (Richardson 1960; Singer and Small 1972; Wilkinson 1980) or in electronic data bases (White 2003; International Institute of Strategic Studies 2003; International Peace Research Institute 2004).

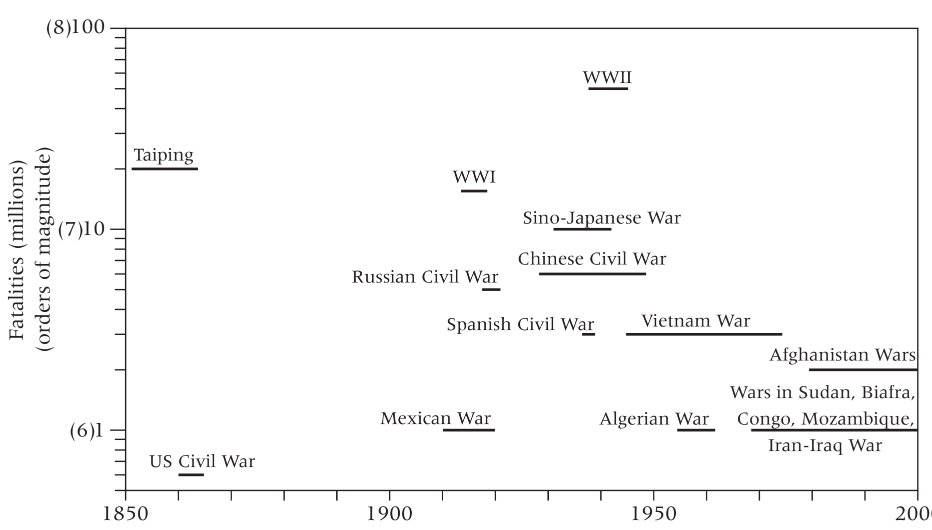
Even a cursory examination of this record shows yet another aspect of that terrible toll, the fact that so many violent deaths had no, or perhaps only a vaguely marginal, effect on the course of world history. Others, however, contributed to outcomes that truly changed the world. Large-scale death tolls of the twentieth century that fit the first category include the Belgian genocide in the Congo (that began before 1900), Turkish massacres of Armenians (mainly in 1915), Hutu killings of Tutsis (1994), wars involving Ethiopia (Ogaden, Eritrea, 1962–92), Nigeria and Biafra (1967–70), India and Pakistan (1971), and civil wars and genocides in Angola (started in 1974), Congo (since 1998), Mozambique (1975–93), Sudan (1956 and perhaps finally finished in 2005), and Cambodia (1975–78). Even in our greatly interconnected world, such conflicts can cause deaths of more than one million people (as did all of the just-listed conflicts, with the highest estimated death tolls for a few of them exceeding 2 million), and some of them can go on for decades, without having any noticeable effect on the cares and concerns of the remaining 98 to 99.9 percent of humanity.

In contrast, the modern era has seen two world wars and a number of interstate conflicts that resulted in long-lasting redistribution of power on a global scale. And there were also intrastate wars that led to the collapse or emergence of powerful states. There is no canonic list of such transformational wars of the nineteenth and twentieth centuries. While the key events are obvious, I also readily concede that a more liberal definition of (indirect) worldwide impacts could extend their list. A long-term transformational effect is the key criterion for inclusion in this category, but all but one of the conflicts I have selected also share another commonality: they could be labeled as megawars, claiming the lives of more than 1 million combatants and civilians. Or, according to Richardson's (1960) definition based on the decadic logarithm of total fatalities, all but one would be magnitude 6 and 7 wars. Their fairly restrictive enumeration starts with the Napoleonic wars (begun in 1796 with the conquest of Italy) that ended in 1815 in a refashioned—and for the next 100 years also a remarkably stable—Europe.[18]

The next entry on my list (see Figure 5) is the protracted Taiping war (1851–64), a massive millennial uprising led by Hong Xiuquan (Spence 1996). This may seem a puzzling entry to readers not familiar with China's modern history, but the Taiping uprising exemplifies a grand transformational conflict because it was its resolute challenge (rather than the British victory in a short war of 1842 and the acquisition of Hong Kong) that fatally undermined the ruling powers of the Qing dynasty (at that time the ruler of the world's largest economy), enmeshed foreign actors in China's politics for the next 100 years, and brought, in less than two generations, the end of the old imperial order (and cost more lives, about 20 million, than the aggregate combatant and civilian losses of World War I).

Conversely, the American Civil War (1861–65) should be included because it opened the way to the country's rapid ascent to global economic primacy. America's gross domestic product surpassed that of Great Britain by 1870; by the 1880s the country had become the technological leader and the world's most innovative economy, firmly set on its rise toward the superpower status. World War I (1914–18) traumatized all European powers, utterly destroyed the post-Napoleonic pattern, ushered in Communism in Russia, and brought the United States into global politics for the first time. And, a fact that is often forgotten, it also began the continuing destabilization of the Middle East by dismembering the Ottoman Empire and by leading eventually to the formation of such artificial, and precariously ex-

FIGURE 5 Wars of magnitude 6 and 7 occurring between 1850 and 2000. Plotted fatalities are minimal to average (and heavily rounded) estimates from a variety of sources listed in the text.



isting, states as Jordan (in 1923), Saudi Arabia and Iraq (1932), Lebanon (1941), and Syria (1946).

World War II (1939–45) is the most obvious entry on the list of transformational wars not only because of the sweeping changes it brought to the global order but also because of the decades-long shadows it cast over the rest of the twentieth, and even into the present century. Virtually all of the key post-1945 conflicts that involved the protagonists of World War II (Russia, the United States, and China in Korea; France and the United States in Vietnam; Russia in Afghanistan; superpower proxy wars in Africa) can be seen as actions designed primarily to maintain or to challenge the outcome of that war. Arguably, other conflicts might seem to qualify, but a closer examination shows that they did not fundamentally alter the past but rather reinforced (often at a high cost) the changes set in motion by transformational wars.

The two most obvious cases are the undeclared but no less fatal wars that were waged, by a variety of means ranging from outright mass killings to manmade famines, against populations of the Soviet Union by Stalin between 1929 and 1953, and against China's people by Mao between 1949 and 1976: the actual toll of these brutalities will be never known with any accuracy, but even the most conservative estimates put the combined toll at above 70 million (White 2003). Another arguable change would be to redefine the durations of the listed transformational wars: for example, World War I beginning with the wars in the Balkans in 1912 and ending with the conclusion of the civil war that established the Soviet Union in 1921; World War II starting with Japan's invasion of Manchuria in 1933 and ending with the Communist victory in China in 1949.

Even a restricted list of globally transformational wars adds up to 42 years of conflicts in two centuries, conservatively estimated total casualties (combatant and civilian) of about 95 million, a mean recurrence rate of about 35 years, 17 million deaths per conflict, and an implied probability of a new conflict of that category at roughly 20 percent during the next 50 years. I readily admit that all of these numbers could be reduced by extending the retrospective for another century. The eighteenth century had a remarkably lower intensity of all violent conflicts than the two preceding and the two subsequent centuries (Brecke 1999); but as most of it, and most of the then major powers, belonged distinctly to the premodern era, its exclusion makes sense.

Three primary conclusions emerge from the examination of all armed conflicts of the past two to three centuries. First, an upward trend in the total number of conflicts starting in each decade; second, an increasing share of wars of short duration (less than one year) (Kaye, Grant, and Emond 1985). Implications of these findings for future transformational conflicts are unclear. But the most important finding comes from Richardson's (1960) search for causative factors of war and his conclusion that wars are largely random catastrophes whose specific time and location we cannot predict but whose recurrence we must expect. That would mean that wars are like earthquakes or hurricanes, leading Hayes (2002: 15) to speak of warring nations that "bang against one another with no more plan or principle than molecules in an overheated gas."

At the beginning of the twenty-first century one could argue that new realities have greatly diminished the likelihood of recurrence of many possible conflicts. The European Union is widely seen as a near-absolute barrier to any armed conflict involving its members; America and Russia may not be strategic partners but they are not the same adversaries they were for two generations preceding the fall of the Berlin Wall in 1989; the Soviet Union and China came very close to a massive conflict in 1969 (a close call that soon prompted Mao to turn to the United States), but today China buys the top Russian weapons; and Japan is not about to attack anybody in East Asia. This reasoning would negate, or at least severely undercut, Richardson's argument, but it would be a mistake to use it when thinking about long spans of history. Neither short-term complacency nor the understandable reluctance or inability to imagine the locale or the cause of the next grand transformational conflict is a good argument against its rather high probability.

In 1790 no Prussian high officer or Czarist general could suspect that a diminutive Corsican from Ajaccio, who soon became known to his troops as *le petit caporal*, would set out to redraw the map of Germany before embarking on a mad foray into the heart of Muscovy. In 1840 the Emperor Daoguang could not have dreamed that the dynastic rule that lasted for millennia would come close to its end because of a failed candidate of the state Confucian examination who came to think of himself as a new Christ. And in 1918 the victorious powers, dictating a new European peace in Versailles, would not have credited a destitute, neurotic would-be artist and veteran of trench warfare from Munich with powers large enough to undo, in a mere two decades, their new order and plunge the world into its greatest war.[19]

New realities may have lowered the overall probability of grand, globally transformational conflicts but they have not eliminated their recurrence. Richardson's reasoning and the record of the past two centuries imply that during the next half century the likelihood of another armed conflict whose outcome would have the potential to change the course of world history is no less than about 15 percent and most likely around 20 percent. As in all cases of such probabilistic assessments, the focus is not on a particular figure but rather on the proper order of magnitude: no matter whether the probability of a new transformational war is only 10 percent or 40 percent, it is one to two orders of magnitude higher than that of globally destructive natural catastrophes that I described earlier in this essay.

Relative fears

Determined and concerted actions can modify, even reverse, many seemingly deeply entrenched trends, but as of now there is nothing we can do to avert any low-probability natural catastrophe whose consequences can change the course of history: in this sense our civilization is no different from the cuneiform or hieroglyphic realms of the Middle East of 5,000 years ago, or from the early modern world of the seventeenth century. We are getting better at anticipating some volcanic activity—clear warnings given ahead of Mount Pinatubo's 1991 eruption were perhaps the greatest success (Newhall, Hendley, and Stauffer 1997)—but discerning the likely magnitude of an eruption remains beyond our ken, as does the ability to predict a major earthquake.

Surprisingly, we may soon be able to do something in space rather than on Earth. As already noted, by the end of 2008 we will have surveyed all near-Earth objects larger than one km in diameter and will be able to calculate the risk of a very large-scale terrestrial impact with unprecedented accuracy. Moreover, at the current rate of discovery some 90 percent of all near-Earth objects large enough to pose a global risk should be detected by the year 2020 (Rabinowitz et al. 2000). So far, observations of known objects and computations of their trajectories have not discovered an object on a collision course with the Earth, but theoretical proposals have already been made for possible deflection of asteroids (Milani 2003). Such an operation (contrary to first impressions) is not a matter of wishful science fiction: it is likely that it could be accomplished with a relatively limited discharge of energy, just enough to deflect the object from its collision-bound trajectory.

Appraisals of natural catastrophes that can have a nearly instantaneous effect as well as generations-long worldwide consequences show low probabilities during the next half century—but, at the same time, such quantifications enter a realm that is alien even to those experts who routinely analyze various risks. Leading hazards encountered in modern society have a fairly high frequency of fatalities but they kill in discretely small numbers, and most of the losses (be it mortality, injuries, or economic damage) are sustained through voluntary actions and exposures whose risks people almost uniformly underestimate. Annual mortality aggregates of such exposures may be relatively high but they come to public attention only if a particular event of that kind is unusually large.

Car accidents are perhaps the best example of the peculiar attitude with which humans treat voluntary risks that have a high-frequency rate but a low-fatality rate per event. They now cause worldwide nearly 1.2 million deaths a year (WHO 2003), but more than 90 percent of individual events involve the killing of just one or two people; these events are widely reported only when the per-event mortality rate rises (albeit in absolute terms it still remains fairly small): fog- or ice-induced pile-ups of scores of cars causing a dozen or more casualties are the most common instance. In sharp contrast is the attitude toward terrorist attacks: their fatalities are large, their potential dangers are real, but it is our self-inflicted terrorizing that wildly exaggerates both their likely frequency (the notion of ubiquitous complex terrorism) and their impact (suitcase nuclear bombs devastating cities, new bioterror plagues killing on massive scales).

Failures of machines (airplanes, trains, ferries) or their control systems (or, more likely, of their operators) that result in hundreds of deaths are rare. Natural catastrophes that kill almost instantly tens or hundreds of thousands are very rare and, as has been clearly illustrated with the December 2004 Indian Ocean tsunami, they elicit incredulity at the scope of their destructive impact. But even mortality on this scale does not matter in terms of world history. Even if the latest tsunami toll were to surpass 300,000, it would be nowhere near the record level for a modern natural catastrophe—and none of those left any long-lasting mark on global affairs. Most notably, every one of China's recurrent (and now almost totally forgotten) droughts during the first half of the twentieth century (1907, 1928, 1936, 1941) claimed at least one million people, as did the Huanghe flood in 1931. And in an entirely different world, with weather satellites and electronic telecommunication, the Bhola cyclone still killed about half a million people in East Pakistan in 1970.

We must remain agnostic about the eventual impact of what Rapoport (2001) called the fourth wave of terror.[20] Historical lessons are clear: ending terror everywhere is not a likely outcome of even the most dedicated and most taxing effort. Terrorism is deeply rooted in modern culture and even a virtual eradication of one of its forms or leading groups settles little in the long run as new forms and new groups may emerge unexpectedly (as did plane hijackings in the 1960s and *al-Qaida* in the 1990s). The real question is about the intensity and frequency with which terrorist actions can be sustained over a long time period, and the unknown course of those two variables will determine their eventual impact on modern history.

Good arguments can be made for seeing terrorist actions as a shocking (also painful and costly) but manageable risk among other risks and to point out the general tendency to exaggerate the likelihood of new, infrequent, but spectacular, threats. On the other hand, it is understandable why a responsible political leadership would tend to see terrorism as an unprecedented, and intolerably deadly, challenge to the perpetuation of modern open societies. In any case, nobody can assign any meaningful probabilities to these different outcomes, whereas a clear judgment is possible regarding any future natural catastrophes: in order to leave a mark on world history they would have to be on scales not experienced during the historic era and would have to claim, almost instantly or within a few months, many millions of lives. Events of sufficient magnitude to produce such a toll took place within the past million years, but none of them has probabilities higher than 0.1 percent during the next 50 years (Figure 6).

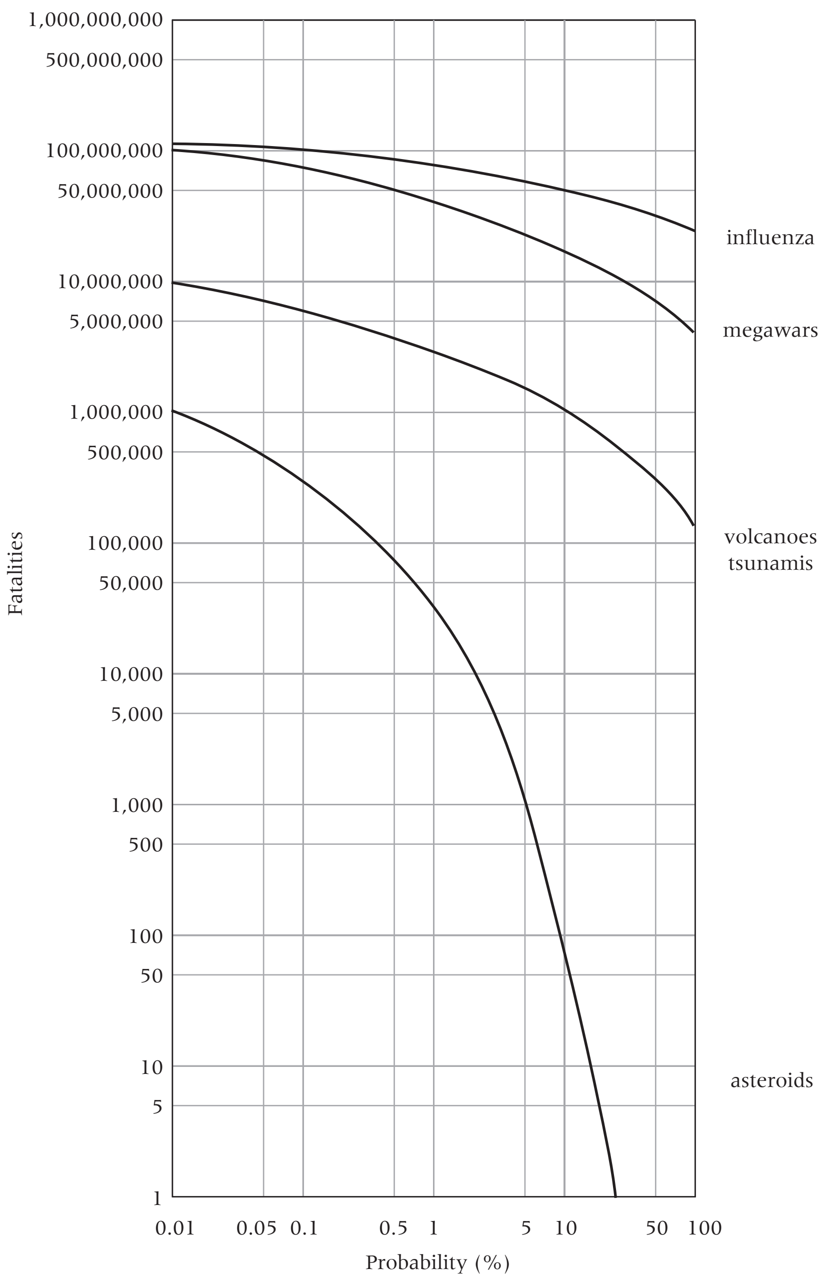
In contrast, there is a high probability of an influenza pandemic that would rival or surpass the greatest such event on record, and a simple probabilistic assessment shows that the risk of a transformational megawar is of the same order of magnitude (Figure 6). But I emphasize that the past record, while highly indicative and inevitably suggestive, is basically one of singularities, events that are too few and mostly too far apart to allow for any meaningful statistical evaluation beyond the simplest calculations of highly uncertain return frequencies and approximate recurrence probabilities. Still, we now know enough about near-Earth objects to rank the danger from colliding asteroids as by far the least likely discontinuity with a potential to change near-term history. Moreover, the overall risk may be revised substantially downward during the coming years.

We can take many steps to lessen the risk of a future megawar and even to reduce the likelihood of the worst imaginable terrorist attacks, but we are entirely at the mercy of unpredictable viral mutations. With luck the next pandemic may resemble much more the last bout than the 1918–19 event, or it could be the greatest viral cataclysm in history. These are, indeed, the most disturbing marks of our ignorance: we have no way to know whether we are exaggerating or underestimating what is to come, be it from the depth of fundamentalist hatred or from random mutations of viral genomes. We can take many steps to be better prepared for another terrorist attack on the scale of 9/11 and for a pandemic mortality on the scale of the two last episodes. But if we are grossly underestimating these risks, then there is much less we are likely to do to make any fundamental difference: there is simply no way to prepare for a terrorist attack with a hijacked nuclear-tipped missile or for dealing with more than 2 billion infected people and more than 100 million deaths.

But many steps we can take will make a marginal difference, and those margins may translate into a large number of saved lives. The probability of a terrorist campaign that would be sufficiently intense and prolonged to change the course of history is unknown and unknowable. Even so, a combination of rational steps (in contrast to the exaggerated, often plainly cosmetic, and patently wasteful post-9/11 responses) ranging from better evaluation of available intelligence (still marred by shortages of translators and coordinated data bases) and more flexible armed response to gradual social and political transformations can clearly reduce the likelihood of many terrorist attacks and moderate their consequences.

But if we are to act as rational risk minimizers, then the current preoccupation with this risk should not blind us to what are historically two much more likely threats: another megawar and another pandemic during

FIGURE 6 Probabilities of massively fatal discontinuities during the next 50 years, ranging from low chances of asteroid impacts to a high probability of a virulent influenza pandemic. Starting points at the right vertical axis are calculated on the basis of the historical record of the past two centuries; all curves are approximations, aiming primarily to convey correct orders of magnitude



the next 50 years. Early interventions to defuse any emerging causes of potentially massive armed confrontations and better preparedness for a major pandemic would be the most rewarding risk-reducing steps. Forget about near-Earth asteroids, supervolcanoes, and monster tsunamis; with foresight and some luck we can even live with terrorism, but we must not underestimate the chances of another megawar and must remember that unpredictably mutating viruses will be always with us.

Notes

1 On Fukuyama: he rightly complains that he has been misunderstood since he did not suggest that events will come to an end. What he maintains is that no matter how large and grave future events will be, history itself ("as a single, coherent, evolutionary process") is over because nothing else awaits but an eventual triumph of liberal democracy. This claim irritates because of its combination of wishful thinking and poverty of imagination: if we were to believe it, then the attacks of 9/11, fundamentalist Islam, terrorism, nuclear blackmail, globalization of the labor force, and the resurgence of China are nothing but inconsequential events because "all of the really big questions had been settled."

On Nineveh: I am far from convinced, despite the enormous challenges we face, that our civilization will be soon transmuted into a defunct heap. And even if it were the case, we would still not be one with Nineveh: myriads of our artifacts made of billions of tonnes of steel, other metals, glass, and plastics that we leave behind will be better preserved, especially once buried, than the Assyrian Empire's short-lived capital of clay that was so thoroughly destroyed by invading Babylonians.

2 Some of these scenarios are available at a staggering cost. For example, Global Business Network's *GBN Scenario Book 2003: History in Motion* (127 pages of spiral-bound text, graphs, and collages) is available to organizations (but not individuals) only as part of an annual US$40,000 subscription. See «www.gbn.com».

3 Several remarkable discontinuities are embedded in the fossil record, none more so than the great Cambrian explosion of highly organized and highly diversified terrestrial life. This great evolutionary jump began about 533 million years ago and it had produced—within a geologically short spell of just 5 to 10 million years, equal to less than 0.3 percent of the entire evolutionary span—virtually all of the animal lineages that are known today (McMenamin and McMenamin 1990).

4 For comparison, Bostrom (2002), in his study of existential risks (those that could annihilate intelligent life or permanently or drastically curtail its potential) classified them into bangs (extinctions due to sudden disasters), crunches (that thwart future developments), shrieks (resulting in very limited advances), and whimpers (changes that lead to the eventual demise of humanity).

5 Some readers might have noticed that this typology is a differently worded version of an undeservedly maligned enumeration offered by Donald Rumsfeld during his press conference on 12 February 2002 (US Department of Defense 2002):

> Reports that say that something hasn't happened are always interesting to me, because as we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we don't know. But there are also unknown unknowns—the ones we don't know we don't know.

6 A biosphere prone to rapid takeover by a single microorganism could not become differentiated into millions of species, with thousands of them closely interdependent within complex food webs of rich ecosystems and all of them connected through global biogeochemical cycles: symbiosis has been no less critical than interspecific competition for life's survival (Smil 2000; Sapp 1994).

There are even weirder ostensibly science-based suggestions regarding civilization's demise, including the idea that we are living in a simulation of a past human society that is run by a superintelligent entity that can choose to shut it down at any time (Bostrom 2002). In response I would only note that the mind running the exercise has been a very patient one as the simulation has been going on for nearly 4 billion years; or does Bostrom dismiss evidence of the Earth's evolution and our emergence as one of its results?

7 In November 1951 the Soviets deployed their first deliverable fission bomb but a more appropriate year might be 1955 when both superpowers acquired their first nuclear-tipped missiles (Johnston 2005): unlike bombers, launched ballistic missiles cannot be recalled.

8 On a much more mundane level, these situations are akin to avoided fatal car crashes when a few centimeters of clearance makes a difference between death and survival: these events happen worldwide thousands of times every hour, but an individual has only one or two such experiences in a lifetime and these singularities make it impossible to calculate probabilities of any future clean escape.

9 As the fanatics of Aum Shinrikyo discovered, it is not easy to disperse a nerve gas and kill a large number of people even in such a densely populated setting as Tokyo's subway (12 people died as the result of their March 1995 attack), and the US anthrax scare of October and November 2001 was primarily a matter of irresponsibly exaggerated fears rather than of any history-altering medical catastrophe. Indeed, many experts argue that the entire threat of bioterrorism has been vastly overblown (Enserink and Kaiser 2005). Given the enormous amount of money now pouring into US research on potentially deadly anthrax and smallpox (more than half a billion dollars in FY 2004), the work on common pathogens that annually claim millions of lives worldwide gets shortchanged; and (a counterintuitive but credible possibility) there is a much greater danger that a bioterror agent could be released by a disgruntled employee of one of 14 new research super-labs built to handle the most dangerous pathogens, rather than being carried to the US by a fundamentalist zealot in a suitcase.

10 Who now remembers the great American blackouts of 1965 and 1977? And the latest repeat, the US–Canadian blackout of August 2003, provided a remarkable illustration of both technical and social resilience. Caused by a series of preventable technical failures, it affected some 50 million people in the Northeastern United States and in Ontario, and (a perfect example of creating mass havoc) it extinguished all traffic lights and stopped all subway trains in New York. But trading on Wall Street continued, the blackout did not lead to any catastrophic disruption of the region's business or its economic growth, hospitals were able to maintain adequate care, and, despite hot weather, the crime rate actually dropped.

11 The most accessible interdisciplinary source of accurate information on the 2004 Indian Ocean tsunami is Wikipedia's long entries for "Tsunami" and "2004 Indian Ocean Earthquake" at http://en.wikipedia.org/wiki/2004_Indian_Ocean_earthquake and at http://en.wikipedia.org/wiki/Tsunami

12 The explosive power of one metric ton of TNT is equal to 4.18 billion joules (GJ). There is no definite number for the explosive yield of the Hiroshima bomb, but the most authoritative source (Malik 1985) puts it at 15 (±3) kt of TNT.

13 Ice-free land accounts for about 26 percent of the Earth's surface and densely populated regions add up to about 4 percent of such land, or almost exactly to 1 percent of the planet's surface. Hiroshima, with a bowl-like setting that acted as a natural concentrator of the blast, had about 40 percent more fatalities and more destruction with a 15 kt blast than did Nagasaki from a 21 kt explosion. Another complicating factor is that a Tunguska-like blast may not be a point-source event (similar to a nuclear bomb) but rather a plume-forming event (similar to a line of explosive charges) and hence could be caused by much less powerful objects (NEOSDT 2003).

14 This theory relies on studies by Harpending et al. (1993) of mitochondrial DNA that indicate a severe population bottleneck between 80,000 and 70,000 years before present. For its critique and reply see Ambrose (2003).

15 This assumes, for illustrative reasons only, an even downwind distribution; the ac-

tual ash cover would range from several meters to a few centimeters. Based on the effect of previous eruptions (Fisher, Heiken, and Hulen 1997) and assuming prevailing northwesterly winds, this ash-covered area would encompass Wyoming, Colorado, Nebraska, Kansas, and Oklahoma and parts of South Dakota, Texas, New Mexico, and Utah. Thinner layers of volcanic ash could be easily incorporated into soils by plowing, but even the most powerful tractors could not handle deposits of 0.5–1.0 m and an inevitable consequence would be (at least temporary) abandonment of cropping on large areas of the Great Plains. Unstable ash layers would be easily dislodged by heavy rains and spring snow melt, creating enormous flooding and stream silting hazards. The economic costs of such an event could be assessed only generations after it took place.

16 But these are battles with no assured outcomes. The endgame has not been easy in the case of polio owing to an irrational resistance to vaccination in northern Nigeria (Roberts 2004). Pertussis (whooping cough) is coming back among children too young to be vaccinated (Tozzi et al. 2005). And there is a long list of more sinister reemerging infections (Morens, Folkers, and Fauci 2004) with a new journal—*Emerging Infectious Diseases*, published by the Centers for Disease Control and Prevention—devoted to this global challenge.

17 HIV/AIDS has had widespread debilitating impacts (social, mental, economic) in sub-Saharan Africa (where the highest country rates of infection now surpass 20 percent), but its annual global death toll (about 2.8 million in the early 2000s) is less than mortality due to diarrhea and tuberculosis, two diseases that we know perfectly well how to eradicate at an acceptably low cost and that now claim annually about 3.4 million lives (WHO 2003). Moreover, low and steady rates of HIV infection in many countries and falling rates in some previously badly affected nations (particularly Uganda and Thailand) show that the disease can be managed.

18 This century-long stability was not fundamentally altered either by brief conflicts between Germany and Austria and Germany and France or by repeated acts of terror that killed some of the continent's leading public figures (and some, including Kaiser Wilhelm I and Chancellor Bismarck, escaped not just one but two assassination attempts).

19 Failure of imagination is our constant companion as we face new political, economic, and strategic realities. Perhaps the three most spectacular examples of the past generation were the rapid and nonviolent demise of the Soviet Union, the sudden post-1990 retreat of Japan from being the world's leading economy, and, of course, young, well-educated middle-class Saudis and Egyptians steering Boeing 767s into the World Trade Center.

20 According to Rapoport (2001), "Since the 1880s, four successive, overlapping major waves of terror have washed over the world.… The first three lasted approximately a generation each; and the fourth, which began in 1979, is still in process" (p. 420). The year 1979 saw not only the rise of theocracy in Iran but also, symbolically, the beginning of a new century in the Islamic calendar.

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