

H HEURISTICS

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The Architecture of Civilization

Energy, Coordination, Interdependence and the
Conditions for Its Own Survival

Foundations · Organization · Interdependence · Global System · Vulnerability · Resilience

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H Heuristics · Architecture of Creation series

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About This Report

This report asks how civilization emerges from individual human activity, organizes itself into increasingly complex systems, and sustains or undermines the conditions required for its continued existence. It belongs to the H Heuristics [Architecture of Creation](#) series. The foundational report asked why the same forms recur across unrelated systems and answered with a layered model in which constraints define a space of viable forms, generative processes explore it, and filters decide what persists. Later reports applied that model to the cosmos in [The Architecture of Creation in the Universe](#), to biology in [The Architecture of Life](#), and to a coupled planet in [The Architecture of Earth](#). [The Architecture of Creation and Development](#) applied it to the diffusion of technology. [The Architecture of Europe's Rise and Dissolution](#) applied it to one civilization's rise. [The Architecture of Entropy](#) supplied the thermodynamic background, and [A Unified Architecture of Reality](#) compared all the domains.

This report turns the framework onto civilization as a whole. It treats civilization as a system of interdependent layers: energy, resources, technology, institutions, information, economic production and social coordination. It asks how these layers generate large-scale order, how they enable development, and how they create vulnerabilities that can spread across societies. The aim is not to argue that civilization follows a set path. History offers no basis for that claim, and the report does not make it. The aim is to identify recurring mechanisms that help explain how civilizations form, expand, resist shocks, change and sometimes decline.

The report is written for researchers, students and policy readers, and for anyone who has wondered how eight billion strangers come to feed, house and supply one another. It combines established findings from archaeology, history, economics, ecology and network science with the H Heuristics framework, and keeps the two apart. Each major claim carries an evidence grade. Analogies are labeled as analogies, and the framework's own propositions are labeled as such.

How to read this report

Each section starts on a new page and can be read on its own. The report has four parts (Figure 1). Sections 1 to 3 set out the question and the central hypothesis, review the main theories of civilization, and state the framework of seven layers and six principles. Sections 4 to 8 work through five dimensions of civilization in rough historical order: its material foundations, the emergence of organized society, the growth of technological complexity and interdependence, the architecture of today's global system, and its vulnerabilities. Sections 9 to 11 look at dynamics. They examine what history shows about collapse and recovery, test the central hypothesis with a quantitative model, and return to the five research questions. Sections 12 to 15 state testable hypotheses, examine the framework's limits, draw out implications and conclude.

FOUNDATIONS

**1. Introduction**

The central question, the hypothesis and what would count as an answer

Section 1

**2. Literature Review**

Energy, geography, institutions, complexity and collapse

Section 2

**3. The Theoretical Framework**

Seven layers, six principles and a formal statement

Section 3

THE FIVE DIMENSIONS

**4. The Foundations of Civilization**

Food surplus, energy, geography, water, density, specialization

Section 4

**5. The Emergence of Organized Society**

Settlements, trade, writing, law, administration, states

Section 5

**6. Complexity, Technology and Interdependence**

Industry, electricity, computing, logistics, finance

Section 6

**7. The Architecture of Global Civilization**

Economies, institutions, supply chains, information, geopolitics

Section 7

**8. Civilization's Vulnerabilities**

Climate, pollution, resources, conflict, inequality, hazards

Section 8

DYNAMICS AND TESTS

**9. Resilience, Collapse and Recovery**

What history shows about shocks, decline and regeneration

Section 9

**10. Testing the Complexity Gap**

Original models of the central hypothesis

Section 10

**11. The Research Questions Revisited**

Five questions, five graded answers

Section 11

EVALUATION

**12. Hypotheses and Research Agenda**

Ten testable propositions

Section 12

**13. The Limits of the Framework**

Determinism, survivorship, data and analogy

Section 13

**14. Implications**

Heuristics for building a durable civilization

Section 14

**15. Conclusion**

Can complexity be managed as fast as it is produced?

Section 15

Figure 1. The structure of the report. Three foundational sections establish the framework, five sections examine the dimensions of civilization, three test its dynamics, and four evaluate the results.

Source: *H Heuristics*.

Blue underlined text is a hyperlink. Where a specific result is cited, links to the primary literature go to its DOI record. Where a concept is introduced, links go to a reference article, and where a statistic is quoted, they go to the data provider. Every DOI was checked against its registered title before publication. A full reference list follows Section 15.

Evidence grades

Claims are graded on the same four-level scale used throughout the series.

Table 1. Evidence grades used in this report

Grade	Meaning	Example from this report
A: Established	Confirmed repeatedly by independent evidence, or following directly from physical or mathematical necessity.	Agriculture arose independently in several regions of the world during the Holocene
B: Well supported	Strong evidence from several lines of work, with unresolved detail or some dissent.	Larger, better-connected populations sustain more complex technology
C: Plausible or contested	A credible mechanism and partial evidence; the field is actively debating it.	Diminishing returns to complexity are a general cause of societal collapse
D: Speculative	A hypothesis offered for testing, labeled as such wherever it appears.	Global civilization's capacity to manage complexity is currently growing more slowly than its capacity to produce it

The grade describes the state of knowledge about a claim, not its importance. Several of the report's most important claims are graded C or D because the evidence needed to settle them does not yet exist.

A note on the figures and calculations

The report contains 23 figures and 15 tables. Ten figures present original models built for this report. They cover the cost of coordinating large groups; settlement growth by cumulative advantage; the link between population size and cumulative skill; cascading failure in production networks; collapse in interdependent infrastructure networks; trade as insurance against harvest failure; diminishing returns to complexity; a race between the capacity to produce complexity and the capacity to manage it; secular cycles of growth and crisis; and recovery under repeated shocks. Each caption says what was computed and with what assumptions. The models are deliberately simple. They show how mechanisms behave, not what will happen to any particular society. The other figures are diagrams drawn for this report or charts of published estimates. Their source lines credit the original data, rounded for display.

How to cite

Hughes, H. (2026). *The Architecture of Civilization: Energy, Coordination, Interdependence and the Conditions for Its Own Survival*. H Heuristics Research Report, Architecture of Creation series. The report synthesizes published research and presents original models and propositions, which are labeled as such.

Executive Summary

Abstract

Civilization is the largest structure humans have built, and no one designed it. It emerged from billions of individual decisions to plant, trade, record, obey, invent and cooperate. Over about twelve thousand years those decisions produced a system that now feeds eight billion people, moves goods and information around the planet in days or milliseconds, and alters the planet's climate and chemistry. This report examines that system as an architecture of seven interdependent layers: energy, resources, technology, institutions, information, economic production and social coordination. It works through five dimensions: material foundations; the emergence of organized society; complexity and interdependence; the architecture of global civilization; and civilization's vulnerabilities. It proposes six principles and states a central hypothesis: civilization's long-term trajectory is shaped by the relationship between its organizational complexity, productive capacity, interdependence and ability to adapt. The report tests this hypothesis with ten original models and a review of historical collapses and recoveries. It concludes that the most useful single distinction is between civilization's capacity to produce complexity and its capacity to manage the consequences of that complexity. Where the second keeps pace with the first, complexity has repeatedly increased resilience. Where it falls behind, a society accumulates hidden exposure that is released through crises. The report finds no law that dooms complex societies. It does find that resilience is not automatic and must be built at the same rate as the complexity it protects.

The question

The defining question of the report is how civilization emerges from individual human activity, organizes itself into increasingly complex systems, and sustains or undermines the conditions required for its continued existence. The question has three parts, and each points to a different kind of mechanism. *Emergence* is about how local actions add up to structures no one intended: cities, markets, states and scripts. *Organization* is about how those structures coordinate ever larger numbers of people through institutions, information and exchange. *Sustenance* is about whether the resulting system maintains the energy, resources, ecological stability and social trust it depends on, or erodes them.

The defining question. How does civilization emerge from individual human activity, organize itself into increasingly complex systems, and sustain or undermine the conditions required for its continued existence?

The thesis

The report's thesis is that civilization is best understood as a race between two capacities that are often treated as one. The first is the capacity to *produce* complexity: to generate surplus, specialize, connect, build infrastructure and invent technologies that let more people do more things. The second is the capacity to *manage the consequences* of that complexity: to detect problems, absorb shocks, repair damage, govern shared resources, settle conflicts and change course. Both have grown enormously over history, but they are driven by different forces and need not grow at the same rate. Production is rewarded quickly and privately. Management is usually rewarded slowly and collectively, and often only after a crisis has shown what was missing.

Central hypothesis. The Civilizational Architecture Hypothesis: civilization's long-term trajectory is shaped by the relationship between its organizational complexity, productive capacity, interdependence and ability to adapt to changing conditions.

Principal findings

- 1. Every civilization rests on an energy and material surplus (Grade A).** No complex society has existed without a reliable surplus of food and energy that frees people from producing it. Energy capture per person rose roughly 46-fold from foraging to the technological society of the 1970s United States, and today's world average is about 50,000 kilocalories per person per day (Figure 6). The share of workers free to do something other than farm is $1 - 1/s$, where s is the number of people one farmer supports. Moving s from about 1.2, typical of agrarian societies, to about 50, as in the United States today, moved the non-farm share from under a fifth to 98 per cent (Figure 7).
- 2. Coordination at scale requires hierarchy, writing and institutions, because direct relationships do not scale (Grade A for the arithmetic, B for the history).** A state of one million people organized through direct ties would need each person to maintain about a million relationships. With a span of control of ten, it needs six levels of hierarchy, and the whole world would need ten. But if each level relays only 90 per cent of decision-relevant information, just 35 per cent of what happens at the base of a world-scale hierarchy reaches the top (Figure 9). Writing, law, money and bureaucracy are the technologies that civilizations invented to break this limit.
- 3. Large-scale order emerges from local rules (Grade A in models, B in data).** When migrants in our settlement model favor larger and more fertile places, a few thousand villages grow into a heavy-tailed urban hierarchy in which the ten largest centers hold 88 per cent of the population. Without that cumulative advantage, the ten largest hold under 2 per cent (Figure 10). No planner is needed for cities, capitals and hinterlands to appear.
- 4. Accumulated knowledge depends on population size and connection, and can be lost (Grade B).** In Henrich's model of cumulative culture, computed here, a skill of moderate difficulty is maintained only if about 620 or more people learn from one another. Isolating a population of 4,000 down to 200 reverses its progress (Figure 11). Accumulation is real but not guaranteed.
- 5. Interdependence multiplies output and fragility together (Grade A in models, B in data).** In our production-network model, a single-sourced supply chain four tiers deep with four inputs per product loses 97 per cent of its final output when only 1 per cent of firms are disrupted. A simple two-by-two chain loses 7 per cent. Adding a second supplier for each input cuts the loss in a six-by-six chain from 100 per cent to 2 per cent at 2 per cent disruption, but one chokepoint input with only two producers raises the chance of losing more than half of output from zero to 6 per cent of shocks (Figure 14). Coupling two infrastructure networks makes them fail abruptly. In our simulation the coupled pair collapsed completely when 40 per cent of one network's nodes were knocked out, a shock that left an uncoupled network 53 per cent functional (Figure 15).
- 6. Global integration insures against local shocks but not against correlated ones (Grade A in models).** Pooling harvests across twenty regions cuts the annual chance of a 15 per cent food shortfall from about 11 per cent to virtually zero when regional shocks are independent. When shocks are 80 per cent correlated, as they increasingly may be under climate change, pooling cuts the risk only to about 8 per cent (Figure 17).
- 7. Vulnerabilities interact more than they add (Grade B).** Climate change, pollution, resource stress, conflict, institutional weakness, inequality and technological hazards amplify one another. In the report's assessment, institutional weakness is the most connected node, both driving and driven by

the others, and conflict is the strongest amplifier (Figure 19). Six of nine planetary boundaries were assessed as transgressed in 2023, and seven in 2025 (Figure 18).

8. **Collapse is usually reorganization, and recovery depends on adaptive capacity (Grade B).** The historical record shows that societal collapses typically involve several interacting stresses, that most are followed by reorganization at lower complexity rather than disappearance, and that some societies recover rapidly from shocks that destroy others. In our recovery model, a society with high adaptive capacity faced with a moderate stream of shocks almost never collapsed within 200 years, while one with no adaptive capacity collapsed 86 per cent of the time (Figure 22).
9. **When production of complexity outpaces its management, crises become the regulator (Grade C; original model).** In our complexity-gap model, when exposure grows faster than management capacity, systemic crises rise from about one per century to a steady state of about 4.4 per century, matching an analytic formula derived here. In that regime, long-run growth depends almost twice as much on the growth of management capacity as on the growth of productive capacity (Figure 23). Doubling productive growth from 2 to 4 per cent a year raised realized growth only from 1.0 to 1.6 per cent.

The verdict

Complexity is neither civilization's destiny nor its doom. The historical and quantitative evidence assembled here supports a conditional answer to the central question. Civilization emerges when energy surpluses, dense settlement and specialization make coordination worth its cost. It grows more complex when institutions, information systems and markets let cooperation extend beyond personal ties. It sustains itself only while its capacity to detect, absorb and correct the consequences of that complexity keeps pace with the complexity itself. The global civilization of the 2020s has produced complexity at an unprecedented rate. Whether its capacity to manage the consequences is growing as fast is the most important open question the report identifies. The report's working judgment, graded D because it cannot yet be measured well, is that it is not.

In one sentence. Civilization lasts not by avoiding complexity but by building the capacity to manage complexity as fast as it builds the complexity itself.

01

INTRODUCTION



1. Introduction

1.1 From individual action to global order

On an ordinary morning, a person in almost any city of the world can eat bread made from wheat grown on another continent. They can drink water treated by chemicals made in a third, read news relayed through undersea cables, and pay for all of it with digital money settled across banks they will never see. None of the thousands of people involved in that morning know one another. None of them planned the system that coordinates them. Yet the system works, most days, with a reliability that would have astonished anyone living before about 1850.

That system is what this report calls civilization: the large-scale organization of human activity that lets very many people specialize, cooperate, accumulate knowledge and transform their environment far beyond what any small group could achieve. It is the most complex structure humans have produced and also the youngest major structure in the [Architecture of Creation](#) series. The universe took billions of years to build galaxies, and life took billions to build multicellular bodies. Civilization went from the first farming villages to a planetary economy in about twelve thousand years. Most of that change happened in the last two centuries (Figure 2).

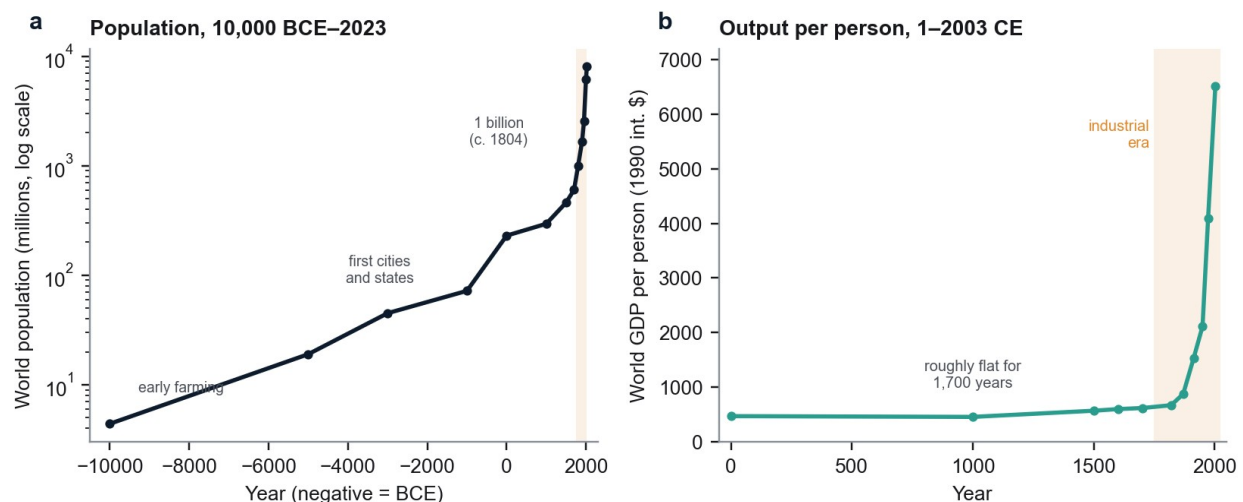


Figure 2. Twelve thousand years in two charts. World population grew slowly for most of the Holocene and then rapidly after about 1750 (a). Output per person barely changed for seventeen centuries and then rose nearly tenfold between 1820 and 2003 (b). The shaded band marks the industrial era.

Source: H Heuristics, from population estimates of the [HYDE 3.2 database](#) and the [UN World Population Prospects](#), and output estimates of [Angus Maddison](#) in 1990 international dollars. Values rounded.

The speed and scale of this change raise the question at the center of this report. How does civilization emerge from individual human activity? How does it organize itself into increasingly complex systems?

And how does it sustain, or undermine, the conditions required for its own continued existence? World population is about eight times its 1800 level. Output per person rose nearly tenfold between 1820 and 2003, after rising by about a third in the previous seventeen centuries. The same period brought nuclear weapons, a changing climate, the loss of a large share of the world's wild animals, and financial and supply-chain crises that spread worldwide within weeks. The capacity that built the modern world also created new ways for it to fail.

1.2 The central question and its three parts

Central question. How does civilization emerge from individual human activity, organize itself into increasingly complex systems, and sustain or undermine the conditions required for its continued existence?

The question has three parts, and each calls for a different kind of explanation.

1. **Emergence.** How do the actions of individuals and small groups add up to structures that no one intended? Cities, markets, scripts and states were not designed in advance. They arose from many local decisions about where to live, what to grow, whom to trade with and whom to obey. Explaining emergence means identifying the local rules and material conditions that make large-scale order likely.
2. **Organization.** How do those structures coordinate ever larger numbers of people? A band of thirty foragers can run on personal knowledge and face-to-face negotiation. A state of a million people cannot. Explaining organization means identifying the technologies of coordination, such as writing, law, money, bureaucracy, markets and digital networks, and the costs and limits of each.
3. **Sustenance.** Does the resulting system maintain the energy, resources, ecological stability, institutional capacity and social trust it depends on, or does it erode them? Explaining sustenance means examining how civilizations respond to stress, why some recover from shocks that destroy others, and whether today's global civilization is building resilience as fast as it builds exposure.

The report treats civilization as a system of interdependent layers: energy, resources, technology, institutions, information, economic production and social coordination. Each layer depends on those below it for inputs and is shaped by those above it through demand, rules and feedback. A disturbance can begin in any layer and spread to the others. Section 3 sets out this structure in detail.

1.3 The Civilizational Architecture Hypothesis

The report's organizing proposition is stated as a hypothesis, not a conclusion.

The Civilizational Architecture Hypothesis. Civilization's long-term trajectory is shaped by the relationship between its organizational complexity, productive capacity, interdependence and ability to adapt to changing conditions.

The hypothesis is phrased in terms of a *relationship* on purpose. It does not say that complexity is good or bad, that growth is sustainable or unsustainable, or that civilizations rise and fall on a schedule. It says that outcomes depend on how four quantities move relative to one another. A society that becomes more complex and more interdependent while its ability to adapt grows faster may become more resilient. A society whose complexity and interdependence outrun its ability to adapt is accumulating risk, even if every indicator of output is rising. The hypothesis produces five research questions, which organize the evidence throughout the report and are answered in Section 11.

1. Does increasing complexity improve resilience, or does it eventually create dependencies that exceed institutional capacity?
2. When does technological progress translate into broad improvements in human welfare?
3. Can societies maintain high levels of complexity while reducing environmental damage and catastrophic risk?
4. Why do some civilizations recover from severe shocks while others experience prolonged decline or fragmentation?
5. Can global civilization develop institutions and infrastructure that allow its components to converge toward safer, more prosperous conditions?

1.4 Producing complexity and managing it

One distinction runs through the whole report: between civilization's **capacity to produce complexity** and its **capacity to manage the consequences of that complexity**. The first is the ability to generate surplus, specialize, build infrastructure, connect markets and invent new technologies. The second is the ability to detect problems, absorb shocks, maintain what has been built, govern shared resources, settle conflicts and change course when circumstances change.

The two capacities are easy to confuse because they often grow together. A richer society can afford better hospitals, larger grain reserves and more capable courts. But they are driven by different forces. Production of complexity is usually rewarded quickly and privately: a firm that lengthens its supply chain to cut costs captures the saving at once. Management of complexity is usually rewarded slowly and collectively: the benefit of a strategic reserve, a redundant supplier or a well-funded public health agency appears only when a shock arrives, and is shared by many who did not pay for it. There is therefore no reason to expect the two to grow at the same rate, and some reason to expect production to run ahead (Figure 3).

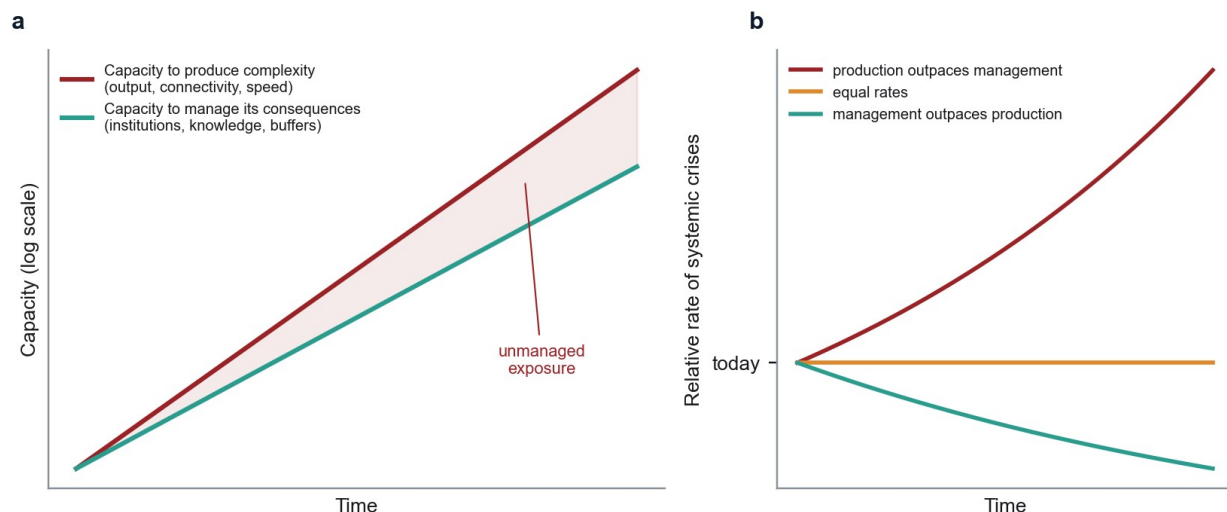


Figure 3. The complexity gap, as a concept. When the capacity to produce complexity grows faster than the capacity to manage its consequences, unmanaged exposure accumulates (a). The rate of systemic crises then depends on whether the gap is widening, stable or closing (b). Section 10 turns this sketch into a quantitative model.

Source: H Heuristics. Illustrative.

Most of the report's original contribution follows from taking this distinction seriously. Section 10 builds a simple model in which the two capacities grow at independent rates, shocks arrive at random, and crises occur when exposure exceeds management capacity. The model shows that when production outpaces management, crises become the mechanism that brings them back into line, and that in this regime long-run growth depends more on management than on production.

1.5 What would count as an answer

A framework that claims to explain civilization must say in advance what would count as success. The report uses four criteria.

1. **Coverage.** The framework should apply to civilizations across time and region, from early Mesopotamia and Mesoamerica to the global system of the 2020s, without special pleading.
2. **Mechanism.** It should identify causal mechanisms, not only patterns. Saying that complex societies collapse is a pattern. Saying that they collapse when the marginal return on complexity becomes negative, and showing how to measure that, is a mechanism.
3. **Discrimination.** It should distinguish cases that turned out differently: societies that recovered from shocks and those that did not, technologies that spread welfare and those that concentrated it.
4. **Falsifiability.** It should state observations that would show it to be wrong. Section 12 lists ten hypotheses, each with a test that could fail.

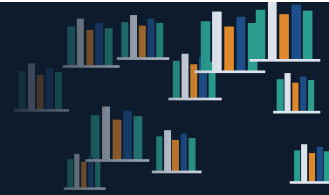
1.6 Method and scope

The report combines four kinds of evidence. It synthesizes published research in archaeology, history, economics, ecology, complexity science and risk analysis, linking to primary sources where specific results are cited. It uses long-run data series compiled by others, rounded and credited. It builds ten original models to clarify mechanisms that are hard to see in the historical record, such as how cascading failure scales with the depth of a supply chain. And it applies the H Heuristics framework to organize the whole.

Three limits of scope should be stated at the outset. First, the report treats civilization in the singular, as the whole interconnected system of human societies, while drawing on the history of particular civilizations as evidence. It does not rank civilizations or compare their cultural worth. Second, the models are deliberately simple. They show how mechanisms behave, not what will happen to any specific country or decade. Third, the historical record is uneven. Literate, well-studied societies are overrepresented, and the evidence for many collapses and recoveries is contested. Section 13 discusses these limits in detail.

02

LITERATURE REVIEW



2. Literature Review: Theories of Civilization

2.1 What a civilization is

The word *civilization* has carried a great deal of baggage, much of it used to rank societies as advanced or backward. This report uses the term in a narrower, descriptive sense that has become standard in archaeology and complexity science: a society organized at a scale beyond kinship and personal acquaintance, sustained by a food surplus, and coordinated by specialized institutions. In 1950 the archaeologist V. Gordon Childe proposed ten criteria for what he called the [urban revolution](#), including cities, full-time specialists, a surplus collected by a central authority, monumental building, a ruling class, writing, exact sciences, art, long-distance trade and a state organization based on residence rather than kinship. Later work showed that not every early civilization had every trait. The Inca, for example, ran a large empire without a full writing system. Still, the criteria capture the cluster of features that tend to appear together.

Quantitative history has since tested whether that cluster is real. The [Seshat Global History Databank](#) coded hundreds of past societies on dozens of variables measuring scale, hierarchy, government, information systems and money. [Turchin and colleagues](#) found that a single underlying dimension accounts for about three-quarters of the variation across these measures. Societies that are larger also tend to have more levels of hierarchy, more specialized officials, writing, coinage and infrastructure. The features of civilization do travel together, across continents that had no contact with one another (Grade B). This is the empirical basis for treating civilization as an architecture rather than a list of traits.

2.2 Energy and material theories

The oldest family of explanations holds that civilization is, at bottom, a way of capturing and using energy. In 1943 the anthropologist Leslie White proposed what became known as [White's law](#): culture evolves as the amount of energy harnessed per person per year increases, or as the efficiency of converting it into work improves. In 1971 Earl Cook estimated [energy use per person](#) at successive stages of development, from about 2,000 kilocalories a day for early humans living on food alone to about 230,000 for the United States in the 1970s. Section 4 uses his estimates.

Vaclav Smil's work on [energy and civilization](#) has made this tradition quantitative and historically detailed. It traces how each energy transition, from human muscle to draught animals, water and wind, coal, oil and electricity, changed what societies could build. The historian [Ian Morris](#) built a social development index in which energy capture per person is the largest component, alongside urbanization, information technology and war-making capacity. Studies of [social metabolism](#) track the materials societies extract, process and discard. They find that global material use rose about eightfold during the twentieth century. These approaches agree that energy and materials set the outer limits of what a civilization can do (Grade A). They disagree about how much energy explains *within* those limits.

2.3 Geography and environment

A second family of explanations emphasizes geography. Jared Diamond's [Guns, Germs, and Steel](#) argued that Eurasia's head start came from the luck of its biogeography. It had more domesticable plants and animals, and an east–west axis that let crops and livestock spread across similar latitudes. Later quantitative work found that [biogeographic conditions predict the timing of the Neolithic transition](#) and that [cultural traits spread more readily along east–west axes](#) (Grade B). The geography of rivers, coasts and fertile soils clearly shaped where early states appeared, though not deterministically.

Older arguments that large-scale irrigation required despotic states, Karl Wittfogel's [hydraulic empire](#) thesis, have not held up well. Many irrigation systems were built and run by local communities long before states existed. More recent work asks what kind of crop made states possible. [Mayshar, Moav and Pascali](#) found that states arose where people grew cereals, which can be seen, measured, stored and taxed, rather than roots and tubers, which can be left in the ground. In their analysis it was this appropriability, more than land productivity, that predicted state formation (Grade B). James C. Scott's [Against the Grain](#) made a similar argument from the historical record. Geography, in this view, did not cause civilization. It changed the payoffs of the strategies that produced it.

2.4 Institutions and the state

A third family emphasizes institutions, the rules that structure human interaction. Douglass North defined [institutions](#) as the humanly devised constraints that shape political, economic and social behavior, and argued that they explain why some societies sustain growth while others do not. [Acemoglu, Johnson and Robinson](#) used variation in colonial settlement to argue that inclusive institutions, which protect property and spread political power, cause long-run prosperity. They later developed the argument in [Why Nations Fail](#). Their empirical strategy has been debated, but the broad claim that institutions matter for long-run development is now widely accepted (Grade B).

Elinor Ostrom showed that communities can govern shared resources without either privatization or central control, if their institutions have certain [design features](#). These include clear boundaries, rules matched to local conditions, monitoring, graduated sanctions and cheap ways of resolving conflict. Her work matters here because many of civilization's vulnerabilities are commons problems, from the atmosphere to the stability of the financial system. Another strand, associated with [Charles Tilly](#), holds that war made states and states made war: the need to raise armies drove the growth of taxation and bureaucracy. Quantitative work supports a version of this view. [Turchin and colleagues](#) showed that the spread of military technology across Eurasia predicts where large-scale societies arose. A later [comprehensive test of hypotheses](#) using Seshat found that agriculture and military technology were the strongest predictors of social complexity (Grade B).

2.5 Complexity, collapse and cycles

A fourth family asks why civilizations fail. Joseph Tainter's [The Collapse of Complex Societies](#) argued that societies solve problems by becoming more complex, adding administrators, soldiers, infrastructure and information processing. Investment in complexity eventually yields diminishing and then negative marginal returns. A society at that point becomes vulnerable to shocks it could once have absorbed, and collapse, meaning a rapid loss of complexity, can become a rational response. He later reviewed the [archaeology of overshoot and collapse](#). Jared Diamond's *Collapse* emphasized environmental damage, climate change, hostile neighbors, loss of trading partners and, above all, a society's response to its problems.

Peter Turchin's structural-demographic theory treats history as a series of [secular cycles](#) lasting two to three centuries. In each, population growth leads to falling wages, elite overproduction, fiscal strain and eventually a period of instability that resets the system. C. S. Holling's [adaptive cycle](#) describes a similar rhythm in ecological and social systems: growth, conservation, release and reorganization, nested across scales. These theories share an insight that this report takes seriously. The success of a phase of growth creates the conditions for its own crisis.

They have also attracted strong criticism. Archaeologists such as [Karl Butzer](#) have argued that *collapse* is often the wrong word. Many supposed collapses were transformations in which populations survived, cultures persisted and political structures reorganized ([Butzer and Endfield](#)). Critics also note that single-cause narratives, whether environmental or social, rarely survive close examination of particular cases. The report accepts these criticisms and uses *collapse* in Tainter's narrow sense: a rapid, significant loss of established social complexity. It does not use it to mean the disappearance of a people.

2.6 Cultural evolution and accumulated knowledge

A fifth family explains how civilizations accumulate the knowledge they run on. Humans learn from one another with high fidelity, so improvements can build on improvements across generations. This is [cumulative cultural evolution](#). Joseph Henrich showed with a simple model that the size and interconnection of a population determine whether complex skills can be maintained. He used it to explain [the loss of technologies in Tasmania](#) after rising seas isolated the island about ten thousand years ago. [Kline and Boyd](#) found that population size predicts the complexity of fishing tools across Oceanic islands, and [laboratory experiments](#) found that larger groups maintain and improve complex skills better than smaller ones. Michael Kremer's [model of the very long run](#) argued that because ideas are shared, larger populations generate faster technological progress. He used this to explain why population growth accelerated over most of history. This body of work grounds the principle of accumulation in Section 3. Knowledge builds up, but only while the network that carries it is large and connected enough (Grade B).

2.7 Networks, systemic risk and polycrisis

A sixth and more recent family studies the risks created by interconnection itself. The sociologist Charles Perrow argued in [Normal Accidents](#) that systems combining tight coupling with complex interactions will have accidents no one can foresee, however well they are managed. Network science showed that many real networks have [heavy-tailed connectivity](#) that makes them [robust to random failure but fragile to targeted attack](#). It also showed that [interdependent networks](#), such as a power grid and the communication network that controls it, can fail abruptly and completely. Economists found that [shocks to individual firms and sectors can drive aggregate fluctuations](#) through input–output links, and documented how the 2011 Tohoku earthquake [propagated through Japanese supply chains](#).

This work has fed a literature on [globally networked risks](#), [global systemic risk](#) and the [polycrisis](#), a condition in which several crises interact so that their combined harm exceeds the sum of their separate effects. [Homer-Dixon and colleagues](#) described an emerging causal architecture of *synchronous failure*. Slow stresses build up across several systems, and fast-moving shocks then trigger them together. The H Heuristics [Cascading Risk Atlas](#) and related reports belong to this tradition.

2.8 What the literature establishes

These families of theory are often presented as rivals. They are better read as accounts of different layers of the same architecture (Table 2). Energy theories explain the base of the system, geographic theories the distribution of opportunities across space, institutional theories the rules of coordination, cultural-evolution theories the accumulation of knowledge, collapse theories the dynamics of decline, and network theories the risks of interconnection. Each is strongest within its own layer and weakest when it claims to explain everything.

Table 2. Major theories of civilization and the layer each explains best

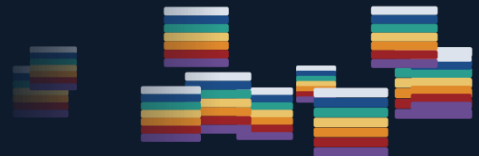
Theory family	Key contributors	Central mechanism	Layer	Main limitation
Energy and metabolism	White; Cook; Smil; Morris; Krausmann	Complexity scales with energy captured per person	Energy; resources	Explains limits better than variation within them
Geography and environment	Diamond; Olsson and Hibbs; Mayshar et al.; Scott	Biogeography and crop type change the payoffs of settlement and taxation	Resources	Risk of determinism; weak on later divergence
Institutions and the state	North; Acemoglu and Robinson; Ostrom; Tilly	Rules shape incentives to invest, cooperate and govern commons	Institutions	Origins of institutions hard to explain
Cultural evolution	Henrich; Boyd; Kremer; Muthukrishna	Population size and connection drive cumulative knowledge	Information; technology	Hard to measure historically
Complexity and collapse	Tainter; Diamond; Turchin; Holling	Success creates costs, rigidity and exposure that lead to crisis	All layers	Collapse often overstated; single causes rare
Networks and systemic risk	Perrow; Barabási; Helbing; Acemoglu et al.; Homer-Dixon	Connectivity spreads shocks; coupling creates abrupt failure	Economy; coordination	Mostly modern evidence; models hard to calibrate

Source: H Heuristics synthesis of the literature cited in Section 2.

Four conclusions are well established (Grade A or B). Complex societies require an energy and food surplus. The features of complexity, such as scale, hierarchy, writing and money, tend to appear together. Institutions that coordinate behavior beyond personal ties are necessary for large-scale order and vary in their consequences. And interconnection both spreads benefits and propagates shocks. What the literature has not established is how these mechanisms combine over time, and in particular whether the growth of complexity tends to outrun the capacity to manage it. That combination is the subject of this report.

03

THE THEORETICAL FRAMEWORK



3. The Theoretical Framework

3.1 Civilization as a layered system

The framework treats civilization as seven interdependent layers (Figure 4). They are ordered roughly by dependence. Each layer draws on those beneath it for inputs, and each is shaped by those above it through demand, rules and feedback. The ordering is not a ranking of importance, and it is not a historical sequence: all seven layers were present in some form in the earliest civilizations. What has changed over time is the scale, speed and coupling of each layer.



Each layer depends on those beneath it for inputs and is shaped by those above it through demand, regulation and feedback. A failure can begin in any layer and propagate in either direction.

Figure 4. The seven-layer architecture of civilization. Each layer supplies something that the layers above it need, and each has characteristic failure modes. Surplus and capability flow upward. Demand, rules and failures propagate in both directions.

Source: H Heuristics framework.

- 1. Energy** is the flow of usable work: food for human muscle, fodder for animals, wood, water and wind, fossil fuels, nuclear and renewable electricity. It is the base layer because every other activity, including thinking, requires it.
- 2. Resources** are the stocks and services that energy acts upon: land, soil, fresh water, forests, fisheries, minerals and the ecosystem services that regulate climate, pollinate crops and purify water.
- 3. Technology** is the set of tools, techniques and infrastructure that convert energy and resources into useful outputs, together with the knowledge to build, operate and repair them.
- 4. Institutions** are the formal and informal rules that structure behavior: property, contracts, law, administration, taxation, states and the international rules that govern relations between them.

5. **Information** is the capacity to record, transmit, store and process knowledge: language, writing, accounting, printing, telecommunications, computation and data.
6. **Economic production** is the organized transformation of inputs into goods and services through the division of labor, markets, firms, capital and supply chains.
7. **Social coordination** is the capacity of people to act together beyond personal ties, sustained by shared identities, norms, trust and the perceived legitimacy of institutions.

The layers are coupled in both directions. Upward coupling is the familiar story of development. An energy surplus frees labor, which supports specialists, who invent technologies, which require institutions to govern their use, which depend on information systems, which make larger markets and wider cooperation possible. Downward coupling is less often noticed but equally important. The economy's demand for energy and materials draws down resources. Institutional choices determine which technologies are developed. Breakdowns in social trust can paralyze institutions, interrupt production and halt investment in energy systems. Civilizational crises usually involve both directions at once.

Table 3. The seven layers: what each supplies, how it is measured, and its major historical transitions

Layer	Supplies	Indicative measures	Major transitions	Typical failure
Energy	Work and heat	Energy use per person; net energy returned on energy invested	Fire; agriculture; draught animals; coal; oil; electricity; renewables	Supply shock; falling net energy
Resources	Materials, water, land, ecosystem services	Material extraction; land use; planetary boundary status	Domestication; irrigation; fertilizer; mining at scale	Depletion; degradation
Technology	Means of conversion	Productivity; diffusion rates; infrastructure stock	Metallurgy; printing; steam; electricity; computing	Lock-in; single points of failure
Institutions	Rules and enforcement	State capacity; rule of law; fiscal capacity	Law codes; bureaucracy; constitutions; international organizations	Capture; fiscal crisis; fragility
Information	Memory and communication	Literacy; storage and bandwidth; data quality	Writing; printing; telegraph; internet; AI	Misinformation; data loss
Economic production	Goods and services	Output; complexity of products; trade	Division of labor; markets; factories; global value chains	Cascading supply failure; financial contagion
Social coordination	Cooperation beyond kin	Trust; legitimacy; social cohesion	Shared religion and identity; citizenship; mass politics	Polarization; legitimacy crisis

Source: H Heuristics framework. Measures are indicative; several are discussed in Sections 4 to 8.

3.2 Six principles of civilizational architecture

Across the seven layers, six principles recur (Figure 5). They are proposed as analytical tools, not universal laws. Each is compared with historical and contemporary evidence in later sections, and each is graded.



Figure 5. Six principles of civilizational architecture. The main sequence runs clockwise: an energy and material base enables coordination, which enables accumulation, which deepens interdependence, which demands adaptive capacity, whose success or failure shapes transformation, which resets the base. At the center is the relationship the report treats as decisive: complexity versus the capacity to manage it.

Source: H Heuristics framework.

- 1. Energy and material foundations.** Every civilization depends on physical resources and on the ability to convert them into useful work. This is the most secure of the principles (Grade A). It follows from thermodynamics, since every organized structure must be maintained against decay by a flow of free energy, as [The Architecture of Entropy](#) explains. It is also confirmed by the historical record: no complex society has existed without an energy surplus.
- 2. Coordination.** Institutions, norms, markets and information systems enable cooperation at scales individuals cannot manage alone (Grade A). Section 5 shows why. The number of relationships needed for direct coordination grows with the square of group size, and human cognition limits stable personal relationships to roughly 150.
- 3. Accumulation.** Knowledge, infrastructure and organizational capabilities build on previous generations, although they can also be lost (Grade B). Accumulation explains why change accelerated over history. The possibility of loss explains why that acceleration has not been continuous.
- 4. Interdependence.** Specialization increases efficiency while making societies reliant on other people, institutions and systems (Grade A for the mechanism, B for its consequences). Interdependence is the principle through which productive gains and systemic risks are most tightly linked.

5. **Adaptive capacity.** Long-term resilience depends on the ability to detect problems, mobilize resources, learn and change course (Grade B). This principle explains why similar shocks have very different consequences for different societies.
6. **Transformation.** Civilizations are not static objects. They can expand, reorganize, fragment or be absorbed into new political and economic structures (Grade A). The principle is a reminder that collapse, in the narrow sense, is usually one form of transformation among several.

Table 4. The six principles: claim, evidence and where each is tested

Principle	Claim	Strongest evidence	Tested in	Grade
1. Energy and material foundations	Complexity requires a sustained energy and material surplus	Thermodynamics; energy capture by stage of development; correlation of energy use with complexity	Section 4; Figure 6	A
2. Coordination	Large-scale cooperation requires institutions and information systems	Scaling of relationships; independent invention of writing, law and money	Section 5; Figure 9	A
3. Accumulation	Capabilities build across generations and can be lost	Population size predicts tool complexity; Tasmania; post-collapse losses	Section 5; Figure 11	B
4. Interdependence	Specialization raises efficiency and creates reliance	Gains from trade; supply-chain cascades; interdependent network failure	Sections 6, 7; Figure 14	A / B
5. Adaptive capacity	Resilience depends on detecting, mobilizing, learning and changing course	Variation in responses to similar shocks; recovery records	Section 9; Figure 22	B
6. Transformation	Civilizations reorganize rather than persist unchanged	Historical record of collapse, conquest, absorption and regeneration	Section 9	A

Source: H Heuristics. Grades as defined in *About This Report*.

3.3 A formal statement

The central hypothesis can be stated in a form that allows it to be modeled and tested. Let C stand for the organizational complexity of a society, meaning the number and diversity of its specialized roles, institutions and connections. Let P stand for its productive capacity and A for its adaptive capacity, its ability to detect, absorb and correct problems. Interdependence is captured by how systemic exposure E grows with complexity. Because the number of potential interactions among components grows faster than the number of components, the report assumes that exposure grows faster than proportionally:

$$E = C^\eta, \quad \eta > 1 \quad (1)$$

The ratio of exposure to adaptive capacity measures how much unmanaged risk a society carries. The report calls it the *complexity gap ratio*:

$$R = E / A = C^\eta / A \quad (2)$$

If complexity grows at rate g and adaptive capacity at rate h , the ratio grows at rate $\eta g - h$. The Civilizational Architecture Hypothesis then says that the sign and size of $\eta g - h$ shape a civilization's trajectory. If it is negative, management outpaces production and the society becomes more resilient as it

becomes more complex. If it is positive, unmanaged exposure accumulates and is periodically released through crises. Section 10 builds this into a stochastic model and derives its long-run behavior.

The formal statement makes two claims explicit that the verbal one leaves vague. First, C and A are different quantities with different drivers, so a society can be rich and fragile, or poor and resilient. Second, what matters is not the level of complexity but its rate of growth relative to the rate of growth of adaptive capacity. A very complex society can be safe, and a modestly complex one can be dangerously overextended.

3.4 Relation to the series framework

The [foundational report](#) of the series describes every creative process in terms of constraints that define a space of possible forms, generators that explore that space, and filters that decide what persists. Civilization fits this description. Its constraints are physical and biological: the energy available, the productivity of land, the speed of transport and communication, and the limits of human cognition. Its generators are innovation, migration, trade, imitation and political entrepreneurship, which keep producing new arrangements. Its filters are competition between firms and states, the success or failure of institutions, environmental feedback and, above all, crises, which remove arrangements that cannot withstand stress.

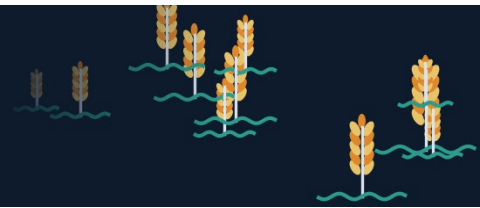
Seen this way, the six principles describe how the generators and filters of civilization operate. Energy and materials set the constraints. Coordination and accumulation are the main generators of complexity. Interdependence links the generated structures together. Adaptive capacity and transformation describe how the filters act. The complexity gap is a statement about the relative speed of generation and filtering. When structures are generated faster than they can be tested and adjusted, the filter acts suddenly and destructively, as crisis.

3.5 What the framework claims and does not claim

The framework claims that civilization can be analyzed as a layered, coupled system; that six principles describe recurring mechanisms across that system; and that the relationship between the growth of complexity and the growth of adaptive capacity is a useful single diagnostic of long-run trajectory. It does not claim that civilization follows a predetermined path, that collapse is inevitable, that complexity is undesirable, or that the variables in the formal statement can yet be measured precisely. It treats the hypothesis as a hypothesis, to be supported or rejected by the evidence assembled in the rest of the report.

04

DIMENSION I · FOUNDATIONS



4. Dimension I: The Foundations of Civilization

4.1 The question

Before there can be cities, scribes or states, there must be enough food and energy for some people to do something other than produce food and energy. This section examines the material conditions that make sustained social organization possible: food surpluses, energy availability, geography, water systems, population density and specialization. It asks why civilizations developed when and where they did, and why they took different forms under different environmental and material constraints. The answer, in brief, is that the foundations set the range of possible civilizations without selecting which one appeared.

4.2 A world that allowed farming

For about 300,000 years anatomically modern humans lived as foragers. Then, within a few thousand years of the end of the last ice age, people in several unconnected regions began to cultivate plants and herd animals. Agriculture was [independently invented](#) in at least seven regions, and possibly more than ten (Table 5). It began in Southwest Asia about 11,500 years ago, in northern and southern China, in New Guinea, in Mesoamerica, in the Andes and Amazonia, in eastern North America and in parts of sub-Saharan Africa (Grade A). [Zeder's review](#) of the Near Eastern evidence shows that the transition was gradual, spread over thousands of years, rather than a sudden revolution.

Why then, and why in so many places at once? The most persuasive explanation is climatic. [Richerson, Boyd and Bettinger](#) argued that the Pleistocene climate was too variable and too low in carbon dioxide for agriculture to be a reliable strategy. The unusually stable climate of the Holocene, which began about 11,700 years ago, made it possible. Once possible, it became close to mandatory, because farming populations grew and displaced or absorbed foragers (Grade B). This is the series' constraint principle at work. The Holocene changed the space of viable strategies, and a strategy that had been unworkable became dominant within a few millennia wherever suitable plants and animals were available.

Table 5. Independent centers of early agriculture and the complex societies that later arose in or near them

Region	Early domestication (years ago, approx.)	Founder crops and animals	Later complex societies (examples)
Southwest Asia	11,500	Wheat, barley, lentils, peas; sheep, goats, cattle, pigs	Sumer and Uruk; Akkad; Babylon; Egypt (with Nile adaptations)
Northern and southern China	10,000–9,000	Millet (north); rice (Yangtze); pigs	Erlitou; Shang; Zhou; Qin and Han
New Guinea highlands	c. 7,000 (earlier claims debated)	Taro, bananas, yams, sugarcane	Dense farming societies without states
Mesoamerica	10,000 (squash); 9,000 (maize)	Maize, beans, squash, chili	Olmec; Maya; Teotihuacan; Aztec
Andes and Amazonia	10,000–8,000	Potatoes, quinoa, squash, manioc; llamas, alpacas	Caral; Chavín; Moche; Wari; Inca
Eastern North America	c. 5,000–4,000	Squash, sunflower, goosefoot	Hopewell; Mississippian (Cahokia)
Sub-Saharan Africa	c. 5,000–4,000	Sorghum, pearl millet, African rice, yams; cattle (adopted)	Aksum; Ghana and Mali; Great Zimbabwe

Source: H Heuristics summary of [Larson et al. \(2014\)](#) and the regional literature. Dates are approximate and several are actively debated. The Indus Valley civilization built on Southwest Asian crops with local additions.

The table shows the first important regularity of this dimension. Similar outcomes arose from different materials. Wheat, maize, rice, potatoes and millet are unrelated plants. They were domesticated by peoples who never met, and in most cases each led, over thousands of years, to cities, writing or record-keeping systems, social hierarchy and states. This is convergence in the sense the series uses the word: different starting materials, shared constraints and similar results. It is strong evidence that civilization is a recurring solution to a recurring problem, not a unique accident (Grade B).

4.3 Energy: the base layer

Every layer of civilization runs on energy. A human body needs about 2,000 to 2,500 kilocalories a day of food. A forager might command about twice that, counting fuel for fire. Earl Cook's [classic estimates](#) trace how energy use per person rose with each stage of development (Figure 6). Early farming brought it to about 12,000 kilocalories a day, with the extra energy flowing through draught animals, fuel and crops grown for fodder. Advanced agrarian societies reached about 26,000, industrial England about 77,000, and the United States of the 1970s about 230,000, roughly 46 times the forager figure. Today's world average, computed from the [Energy Institute's Statistical Review](#) of about 620 exajoules of primary energy a year, is about 50,000 kilocalories per person per day.

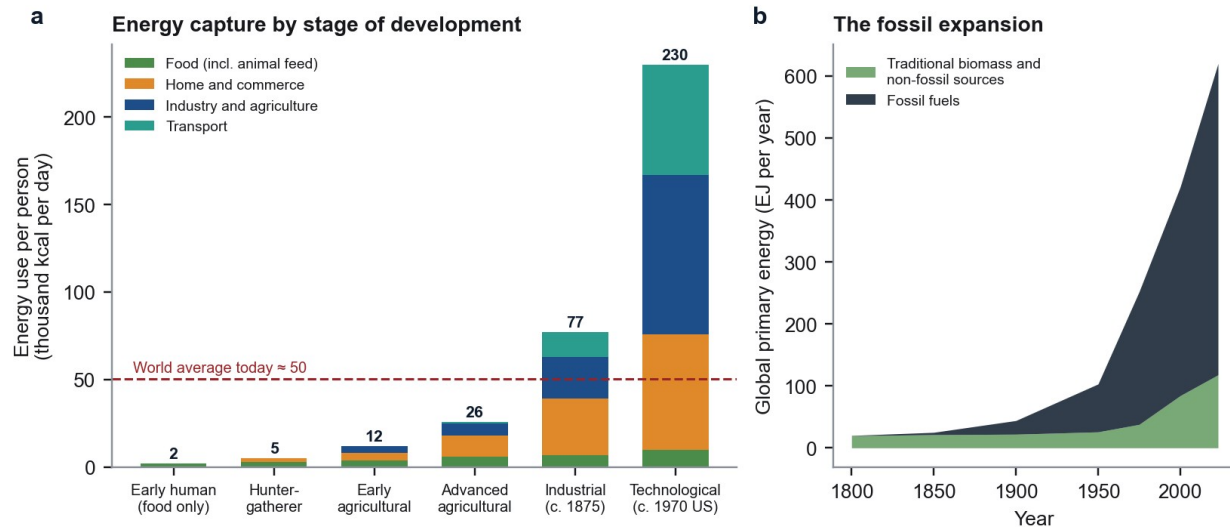


Figure 6. The energy base. Energy use per person at successive stages of development, divided by end use (a). Global primary energy use since 1800, divided into fossil and other sources (b). The dashed line in (a) is today's world average, computed as 620 exajoules shared among 8.06 billion people.

Source: H Heuristics, from [Cook \(1971\)](#), [Our World in Data](#) (after Smil) and the [Energy Institute Statistical Review](#). Values rounded; fossil shares approximate.

Three features of this history matter for the framework. First, each energy transition loosened a constraint on every layer above it. Coal freed industry from the location of rivers and forests. Electricity separated where energy is produced from where it is used. The [Haber–Bosch process](#), which uses fossil energy to fix atmospheric nitrogen into fertilizer, broke the ceiling that soil nitrogen had placed on food production. [Erisman and colleagues](#) estimated that by 2008 synthetic nitrogen was supporting nearly half of the world's population (Grade B). In a literal sense, about half of humanity is now made of nitrogen fixed by burning fossil fuel.

Second, energy is unevenly distributed. The world average of about 50,000 kilocalories a day hides a range of more than tenfold between high-income countries and the poorest, and about [685 million people](#) still lacked electricity in 2022. The base layer of global civilization is not one floor but many, at very different heights.

Third, the modern energy base is mostly fossil, and therefore finite and polluting. About four-fifths of global primary energy still comes from coal, oil and gas. The energy foundation that made modern complexity possible is the main cause of the climate change that now threatens it. This is the clearest single example in the report of a layer sustaining and undermining civilization at the same time.

4.4 From surplus to specialization

Energy matters for civilization because a surplus frees people to specialize. The arithmetic is simple. If one agricultural worker produces enough food for s people, then in a closed economy a share $1/s$ of the workforce must farm, and a share $1 - 1/s$ is free to do something else (Figure 7). In most agrarian societies s was between about 1.1 and 1.35, so between about 75 and 90 per cent of people worked the land. The remaining tenth to quarter supported everyone else: rulers, priests, soldiers, artisans, merchants and scribes. Every pyramid, temple, palace archive and imperial army of the ancient world was built and run by that thin layer of surplus.

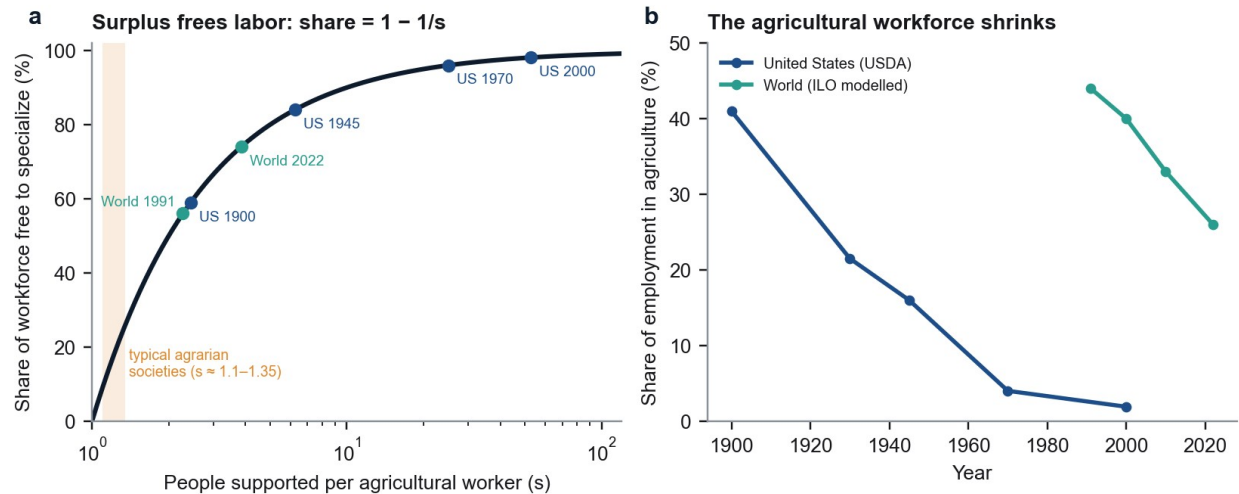


Figure 7. Surplus frees labor for specialization. The share of the workforce free to do non-agricultural work is $1 - 1/s$, where s is the number of people supported by one agricultural worker (a). Points mark the United States from 1900 to 2000 and the world in 1991 and 2022, using s equal to the inverse of the agricultural employment share. The share of employment in agriculture has fallen steeply (b).

Source: H Heuristics. Employment shares from the [US Department of Agriculture](#) and the [International Labour Organization](#) (modeled estimates). Using the inverse of the farm share as s ignores trade and is indicative only.

The curve explains why agricultural productivity is the hidden engine of modern complexity. When s rises from 1.2 to 2.4, the non-farm share rises from about 17 to 58 per cent. That was roughly the US position in 1900. When s reaches about 50, as in the United States today, 98 per cent of workers can do something else. The world as a whole is still in the steep part of the curve. About a quarter of global employment remains in agriculture, so further gains in farm productivity in low-income countries could still release a large share of the world's workforce for other activities. The curve also shows where vulnerability lies. In a society where 98 per cent of people produce no food, the food system is a single point of dependence for almost everyone.

Specialization raised productivity far beyond what the surplus alone implies, because specialists become better at their tasks, invent tools for them and trade with one another. Adam Smith's famous pin factory, in which ten workers dividing the steps between them made about 48,000 pins a day, hundreds of times more than they could have made working alone, captured this. But specialization also creates dependence. Every specialist depends on farmers for food and on other specialists for everything they do not make themselves. The [O-ring theory of economic development](#), proposed by [Michael Kremer](#), formalizes one consequence. When production requires many tasks to be completed successfully, the value of each worker's reliability rises with the number of tasks, and a single failure can destroy the whole product. Section 6 shows how this logic plays out in modern supply chains.

4.5 Geography and water

The earliest civilizations of Mesopotamia, Egypt, the Indus Valley and northern China all grew along great rivers. Rivers offered fertile alluvial soils renewed by floods, water for irrigation, and cheap transport for bulky goods. Irrigation multiplied yields where rainfall was unreliable, and it required collective labor to build and maintain canals. It also created conflicts over water that needed adjudication. Water systems thus linked the resource layer directly to the institutional layer. Early law codes, including that of [Hammurabi](#) in about 1754 BCE, contain provisions on the maintenance of dikes and liability for flooding a neighbor's field.

Geography shaped civilization without determining it. The Andean and Mesoamerican civilizations arose without great navigable rivers and without large draught animals, and they built terraces, raised fields, causeways and storage systems adapted to mountains, lakes and tropical forests. Geography also shaped how fast innovations spread. Diamond's argument that Eurasia's east–west axis let crops and technologies diffuse more easily has [quantitative support](#). And [Olsson and Hibbs](#) found that biogeographic endowments predict the timing of the transition to agriculture, which in turn predicts later development (Grade B). But geography explains the opening positions far better than the later course of history. Some of the regions that led for thousands of years later fell behind, and some latecomers overtook them.

4.6 Density: the double edge of farming

Agriculture supported far more people per square kilometer than foraging, typically ten to a hundred times more. The result was the [Neolithic demographic transition](#), a sustained rise in birth rates visible in cemetery age profiles across the world as farming arrived (Grade A). Density was the precondition for everything that followed. Specialists, markets, armies and the exchange of ideas all require many people within reach of one another.

Density also brought new costs. Early farmers were often shorter and less healthy than the foragers before them. They ate a narrower diet and lived close to domestic animals and their own waste, which encouraged infectious disease. Population growth did not always last. Across Neolithic Europe, [regional populations boomed and then collapsed](#) within centuries of farming's arrival (Grade B). And density made inequality possible on a new scale. [Kohler and colleagues](#) found that wealth disparities, measured by house sizes, rose after the adoption of farming. They rose most in Eurasia, where large domestic animals allowed some households to accumulate far more land and labor than others (Grade B).

These findings show a pattern that recurs throughout the report. The foundations that make civilization possible also introduce vulnerabilities: dependence on a few crops, exposure to disease, demographic boom and bust, and inequality. The first farmers gained capacity and lost some independence and resilience at the same time.

4.7 What the foundations explain

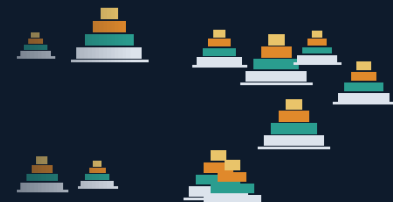
The foundations explain why civilization appeared in the Holocene and not before, why it appeared independently in several regions, and why it appeared first where productive crops, water and transport coincided. They explain why complexity is bounded by energy capture and why the industrial use of fossil fuels allowed an unprecedented expansion. They also explain the first layer of vulnerability. Civilizations depend on a narrow base of crops, energy sources and water systems, and on climatic stability that they did not create.

What the foundations do not explain is the form that civilizations took. Two societies with similar surpluses could organize themselves as a theocracy or a republic, an empire or a league of cities, and could prosper or stagnate. A surplus is necessary but not sufficient. What turns it into a civilization is coordination, the subject of the next section.

Section finding. Food and energy surpluses are necessary for civilization and set its outer limits, but they do not determine its form. The same foundations that enable complexity, including dependence on a narrow resource base and a stable climate, are its first vulnerabilities.

05

DIMENSION II · ORGANIZED SOCIETY



5. Dimension II: The Emergence of Organized Society

5.1 The question

A surplus makes civilization possible. It does not make it happen. Between the first farming villages and the first states lay several thousand years in which people invented the means of coordinating strangers: settlements large enough to need rules, trade networks that crossed cultural boundaries, writing, law, administration and shared beliefs that bound people who would never meet. This section examines how these developments let coordination extend beyond small communities. It also shows how local interactions can generate larger organizational structures without anyone designing them (Figure 8).

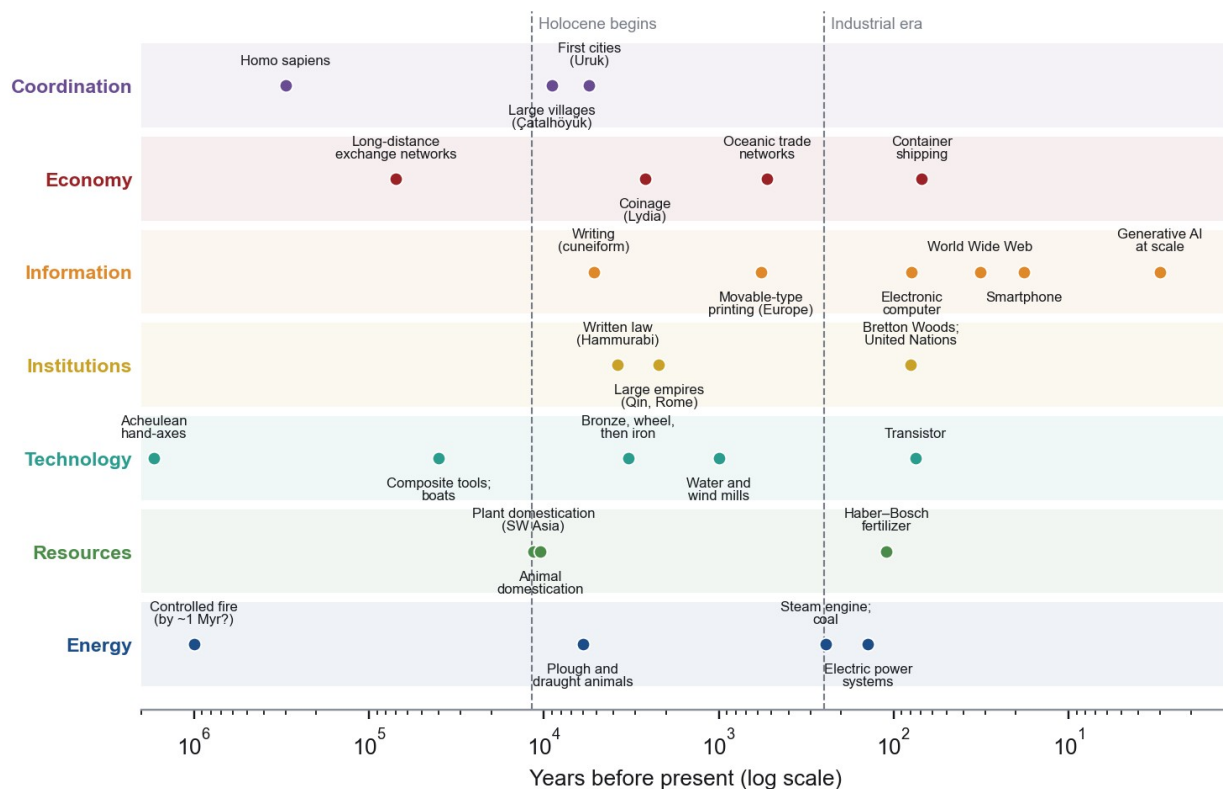


Figure 8. The deep-time architecture of civilization. Selected innovations in each of the seven layers, on a logarithmic time scale. Changes that took hundreds of thousands of years at the left of the chart take decades at the right. The innovations shown are illustrative, not exhaustive, and early dates are approximate.

Source: H Heuristics, from standard archaeological and historical chronologies. Years before 2025.

5.2 Why cooperation does not scale on its own

Human beings evolved to cooperate in small groups. The anthropologist Robin Dunbar related primate group size to the size of the neocortex and predicted that humans can maintain stable personal relationships with about [150 people](#). The figure has been much debated, and the true limit varies with culture and personality. But the broader finding, that human social networks are organized in [a discrete hierarchy of layers](#) of roughly 5, 15, 50 and 150 people, has held up across many datasets (Grade B). Forager societies reflect this structure. A band of a few dozen people belongs to a wider network of a few hundred, linked by marriage and exchange.

Beyond that scale, coordination by personal relationship breaks down for a simple arithmetic reason (Figure 9). In a group of n people where everyone deals with everyone, each person must maintain $n - 1$ relationships and the group as a whole has $n(n - 1)/2$. For a town of 5,000 that is about 12.5 million pairs; for a state of a million it is about 500 billion. Hierarchy solves the problem by routing coordination through intermediaries. If each leader coordinates ten subordinates, no one needs more than eleven relationships, and a million people can be organized in six levels. Eight billion could be organized in ten.

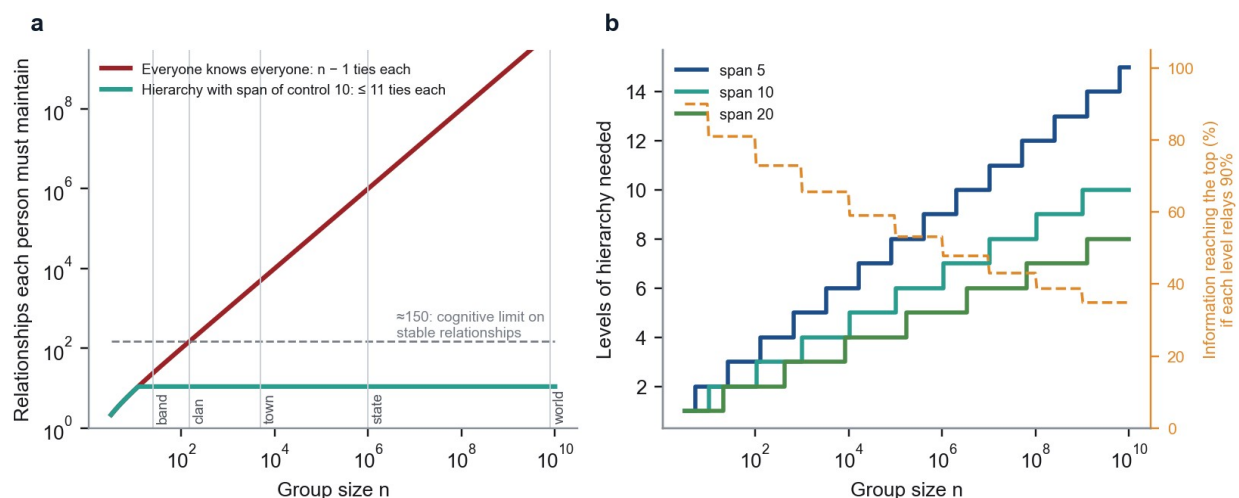


Figure 9. The arithmetic of coordination. When everyone must deal with everyone, the relationships each person needs grow in proportion to group size, exceeding the cognitive limit of about 150 before a group reaches the size of a clan (a). Hierarchy caps the number at the span of control plus one, at the cost of adding levels as the group grows (b). The dashed line shows the share of information reaching the top of a span-10 hierarchy if each level relays 90 per cent of what it receives.

Source: H Heuristics calculation. The 90 per cent relay fidelity is illustrative.

But hierarchy has its own cost, shown by the dashed line in the figure. Every level through which information passes filters, delays and distorts it. If each level of a hierarchy relays 90 per cent of the decision-relevant information it receives, a six-level hierarchy passes 53 per cent of what is known at the bottom to the top. A ten-level hierarchy, enough to organize the whole world, passes 35 per cent. Archaeologists call the version of this problem faced by growing early societies *scalar stress*. As settlements grow, disputes multiply and decision-making slows, until the group either splits or invents new institutions to handle the load (Grade B).

This simple model explains why the history of civilization is, to a large extent, a history of coordination technologies. Each one allowed cooperation to extend further than hierarchy alone permitted, or reduced the information lost as it passed through hierarchy (Table 6).

Table 6. Technologies of coordination: what each made possible and how each can fail

Technology	First appearance (approx.)	What it solved	Scale enabled	Characteristic failure
Kinship and reciprocity	Deep prehistory	Trust among people who know one another	Tens to hundreds	Feuds; inability to absorb strangers
Chieftdom and ritual authority	c. 7,000–5,000 years ago	Decision-making beyond the band; pooling surplus	Thousands	Succession disputes; fission
Writing and accounting	c. 5,200 years ago (Mesopotamia); independently in Egypt, China, Mesoamerica	Memory beyond individuals; tracking obligations	Tens of thousands to millions	Record loss; monopoly of literacy
Written law	c. 4,100–3,800 years ago	Predictable rules among strangers	Cities and kingdoms	Capture by rulers; rigidity
Money and coinage	Coinage c. 2,650 years ago	Exchange without personal credit	Empires and trade zones	Debasement; financial crisis
Professional bureaucracy	Qin and Han China; Rome	Administration by role, not person	Tens of millions	Corruption; rigidity; fiscal overload
Printing	c. 1450 (Europe); earlier in East Asia	Mass replication of knowledge and rules	Nations; science	Propaganda; religious conflict
Telecommunications and the corporation	19th century	Instant coordination at a distance; organizations that outlive founders	Continents	Monopoly; cascading failure
Digital platforms and data	Late 20th century	Matching and coordination of billions in real time	Global	Misinformation; concentration; cyber risk

Source: H Heuristics synthesis. Dates are approximate and refer to the earliest well-attested examples.

5.3 Settlements and the emergence of urban hierarchy

The first large permanent settlements predate states. [Çatalhöyük](#) in Anatolia housed several thousand people about 9,000 years ago without any clear evidence of a ruling class. Uruk in southern Mesopotamia had grown to tens of thousands by about 5,000 years ago and was surrounded by a hierarchy of smaller towns and villages. Wherever states later emerged, a similar pattern appeared: a few large centers, more medium-sized towns and very many villages.

This hierarchy did not need to be designed. Our settlement model shows how it can emerge from a simple local rule (Figure 10). Settlements are founded at random across a landscape, more often where land is fertile. Each new migrant then chooses where to live. In one version of the model, migrants favor places that are already large and fertile, because large places offer more opportunities, more protection and more potential partners. In the null version, they consider fertility alone. The first rule is a form of cumulative advantage, studied by Herbert Simon in the 1950s and known in network science as [preferential attachment](#).

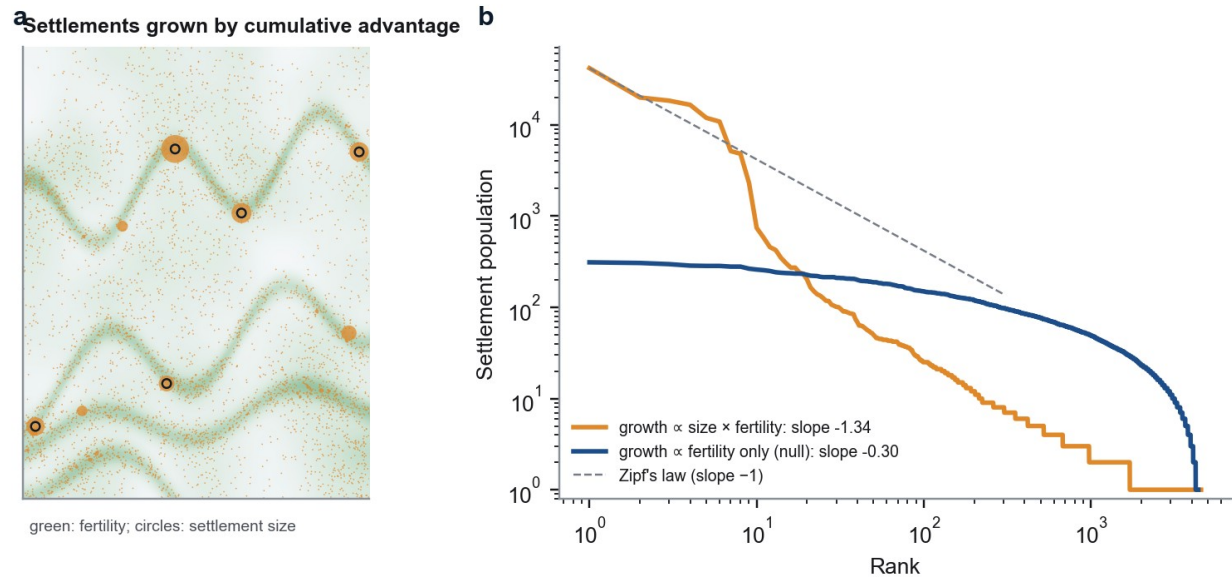


Figure 10. Large-scale order from a local rule. Settlements founded across a fertility landscape and grown by migrants who favor places that are already large and fertile (a). Under cumulative advantage, the rank–size distribution develops a heavy tail, with a few dominant centers. When migrants consider only fertility, it stays flat (b). The dashed line marks Zipf's law.

Source: H Heuristics simulation of 150,000 migrants and 4,555 settlements; new settlements are founded with probability 0.03 per migrant.

The results differ dramatically. Under cumulative advantage, a heavy-tailed urban hierarchy appears. The largest settlement grows to 134 times the size of the largest under the null rule, and the ten largest hold 88 per cent of the population. Under the null rule, the ten largest hold under 2 per cent and the size distribution is flat. The rank–size slope under cumulative advantage is -1.34 , steeper than the -1 of [Zipf's law](#) observed in many national city systems, because the fertility weighting adds extra concentration. The slope under the null rule is -0.30 . The purpose of the model is not to reproduce any real settlement system. It shows that a central place and its hinterland, the basic spatial unit of every early civilization, can emerge from individual decisions without any planner (Grade A in the model, B as an account of history).

Cities, once formed, change the economics of everything in them. [Urban scaling](#) research has found that in modern cities, socio-economic outputs such as wages, patents and GDP grow faster than population, while infrastructure grows more slowly. Section 6 discusses this in detail. Remarkably, [Ortman and colleagues](#) found similar scaling in the settlements of the prehispanic Basin of Mexico (Grade B). The advantages of density that drive modern urbanization appear to have operated in the earliest cities too, which helps explain why cumulative advantage is a reasonable rule for the model.

5.4 Trade: cooperation among strangers

Exchange networks are far older than cities. Obsidian, shells and pigments were moved hundreds of kilometers by foragers tens of thousands of years ago. What changed with civilization was the volume, regularity and institutional support of trade. Mesopotamian cities imported timber, metals and stone in exchange for textiles and grain. By the Bronze Age, trade routes linked the Indus Valley to the Persian Gulf and the Mediterranean, and tin travelled thousands of kilometers to be alloyed with copper.

Trade raises output because it lets each region specialize in what it does relatively best. But it requires solving a problem of trust. A merchant sending goods to a distant partner must believe that payment will

come. Civilizations solved this problem in several ways: through kinship and diaspora networks, merchant guilds with reputational sanctions, temple and palace guarantees, written contracts and, eventually, courts that enforced agreements between strangers. Each solution is an institution that lowered the cost of cooperation beyond personal ties. Trade also created the first long-distance interdependence. When a supplier region suffered drought or war, distant cities felt the loss. Section 9 discusses the end of the Late Bronze Age, the best-known ancient example of a trading system unraveling.

5.5 Writing: memory beyond the individual

Writing was invented independently at least four times: in Mesopotamia about 5,200 years ago, in Egypt at about the same time, in China by about 3,200 years ago and in Mesoamerica by about 2,600 years ago (Grade A). In Mesopotamia it grew out of accounting, using clay tokens and then marks on tablets to record quantities of grain, livestock and labor owed to temples. Most of the earliest texts are receipts, ration lists and inventories. Literature, law and history came later.

The significance of writing for the framework is that it moved memory out of individual heads and into durable, transferable objects. This had three effects. It let administrators track obligations among thousands of people they did not know, extending the coordination limit of Section 5.2. It reduced the information lost as it passed through a hierarchy, because a written order arrives as it was sent. And it let knowledge accumulate across generations without depending on unbroken chains of oral teaching. Writing was not strictly necessary for complex organization. The Inca administered an empire of millions using [khipu](#), knotted cords that recorded numbers and possibly more. But every large state found some way to externalize memory.

5.6 Law, administration and the state

States, meaning organizations that claim the right to tax and to use force over a territory, appeared within a few centuries of writing in Mesopotamia and Egypt, and later in each of the other centers of early civilization. Why states arose remains debated. Classic explanations emphasize the management of irrigation, warfare, trade or class conflict. Recent quantitative work points to the appropriability of the surplus. [Mayshar, Moav and Pascali](#) found that states formed where people depended on cereals that could be seen, measured and taxed. [Allen, Bertazzini and Heldring](#) found that in southern Iraq, shifts in river courses that forced communities to cooperate over irrigation predict the emergence of early state institutions (Grade B).

Whatever their origins, states developed a toolkit of coordination that has changed surprisingly little in form. It includes law codes that set predictable rules, censuses and land registers that make populations visible, taxation that funds collective projects, standing armies and courts that enforce decisions, and bureaucracies that administer by role rather than by personal relationship. The [Code of Hammurabi](#) set out rules on contracts, wages, property and liability. The Qin and Han dynasties of China built a professional bureaucracy recruited partly on merit and administering tens of millions of people. These institutions let states mobilize resources on a scale no chiefdom could match, including for public goods such as irrigation, roads and famine relief. They also concentrated power, and with it the possibility of predation, capture and catastrophic error.

5.7 Shared cultural systems

Institutions work only when enough people accept them. Shared identities, religions, languages and norms supply that acceptance at low cost. People who share a belief that rulers are legitimate, that contracts should be honored and that strangers of the same faith or nation deserve trust need less monitoring and enforcement. Every civilization developed shared cultural systems of this kind, from the temple cults of Sumer and the divine kingship of Egypt to the universal religions and philosophies that spread across Eurasia in the first millennium BCE.

Whether moralizing religions helped cause the growth of social complexity, or followed it, is still debated, and the evidence is contested. What is clear is that social coordination, the top layer of the framework, is a real resource that can be built up and run down. Trust and legitimacy are slow to build, quick to lose and hard to restore. Sections 8 and 9 return to this point, because the erosion of trust is one of the most common features of societies in crisis.

5.8 Accumulation and its fragility

Coordination at scale had a consequence that may be its most important: it allowed knowledge to accumulate. In a connected population, a useful innovation can be copied by many people, improved by some and passed on to the next generation. The larger and better connected the population, the more likely it is that someone will improve a skill and that the improvement will be preserved.

Joseph Henrich formalized this with a [simple model](#), which we compute in Figure 11. In each generation, learners try to copy the most skilled practitioner. Copying is imperfect and on average loses some skill, by an amount α that reflects how hard the skill is to learn. But learners vary, and a few by chance exceed their model. In a large population, the best of these lucky few sets the standard for the next generation, and skill ratchets upward. In a small population, the losses dominate. The expected change in skill per generation is $-\alpha + \beta(\gamma + \ln N)$, where N is the number of learners, β is the spread of copying outcomes and γ is Euler's constant. Skill therefore accumulates only if the connected population exceeds a threshold size:

$$N^* = \exp(\alpha/\beta - \gamma) \quad (3)$$

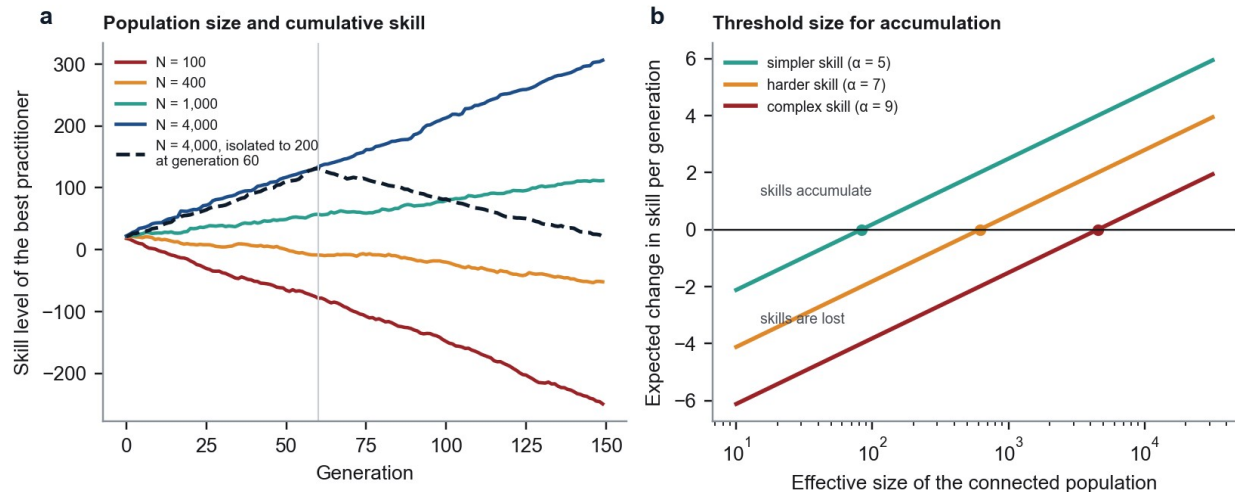


Figure 11. The collective brain. In Henrich's model of cumulative culture, the skill of the best practitioner rises over generations in large connected populations and falls in small ones (a). Isolating a population of 4,000 down to 200 reverses its progress. The expected change per generation rises with the logarithm of population size, so the threshold for accumulation grows steeply with the difficulty of the skill (b).

Source: H Heuristics simulation of [Henrich \(2004\)](#), with $\alpha = 7$ and $\beta = 1$ in (a).

With the values used here, a moderately hard skill is maintained only if about 620 or more people learn from one another. A simpler skill needs about 80. A complex one needs about 4,500, and the threshold rises exponentially with difficulty. In the simulation, a population of 4,000 that had been accumulating skill steadily begins to lose it as soon as it is cut to 200. This is the mechanism Henrich proposed for the loss of bone tools, fishing and cold-weather clothing in Tasmania after rising seas cut it off from mainland Australia. It is supported by [cross-island evidence](#) and [experiments](#) (Grade B).

The implication for the framework is direct. Accumulation is a property of networks, not of individuals, and it is reversible. A civilization's stock of knowledge is maintained only as long as enough connected people continue to practice and transmit it. The loss of literacy across much of the post-Roman West and the Greek mainland after the Bronze Age collapse shows that this is not merely theoretical. Modern civilization depends on skills, such as advanced chip fabrication, that are practiced by very small numbers of people in very few places. This is a form of fragility that Section 7 examines.

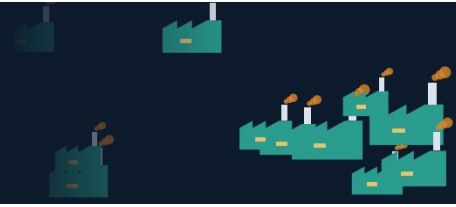
5.9 How local interactions generate large structures

The emergence of organized society shows the series' generative principle operating in human affairs. No one designed the urban hierarchy, the merchant network, the script or the state. Each emerged from many local decisions shaped by constraints and filtered by success. Migrants chose larger places, merchants chose reliable partners, administrators chose record-keeping systems that worked, and communities chose leaders who could manage conflict. The structures that resulted were selected, in the sense that those that coordinated well spread and those that did not were abandoned or absorbed.

Section finding. Organized society emerged because direct cooperation does not scale beyond a few hundred people. Cities, trade, writing, law, administration and shared beliefs are coordination technologies that extended cooperation to millions. Each also concentrated dependence, created new points of failure and made accumulated knowledge reliant on large, connected networks.

06

DIMENSION III · INTERDEPENDENCE



6. Dimension III: Complexity, Technology and Interdependence

6.1 The question

For most of history, civilization's productive capacity grew slowly. Output per person in 1700 was only about a third higher than at the start of the Common Era (Figure 2). Then, over two centuries, industrialization, electricity, computing, global logistics, modern finance and digital communication multiplied it many times over. This section asks how these developments increased civilization's productive capacity, and how they created new dependencies and potential failure points at the same time. Its central finding is that the same structural features that produce the gains, specialization, connection and scale, also create fragility. The two can be separated only by deliberate investment in redundancy and management.

6.2 The industrial break and the Great Acceleration

Industrialization was first of all an energy transition. Coal let Britain, and then other countries, draw on energy stored over millions of years instead of the annual flow of sunlight captured by crops and forests. Steam engines turned that energy into mechanical work, first to pump water from mines, then to drive factories, locomotives and ships. Each later wave, including oil, the internal combustion engine and electricity, extended the range of tasks that fossil energy could perform.

The consequences accelerated after 1950. Earth-system scientists call the post-war surge in human activity the [Great Acceleration](#). Population, GDP, energy use, urbanization, material extraction and greenhouse gas concentrations all rose more steeply in the second half of the twentieth century than ever before (Figure 12). Global material extraction rose from about 7 billion tonnes a year in 1900 to over 100 billion today, according to the [UN International Resource Panel](#). [Elhacham and colleagues](#) estimated that around 2020 the mass of human-made objects, mostly concrete, aggregates, bricks and asphalt, came to exceed the dry mass of all living things on Earth (Grade B).

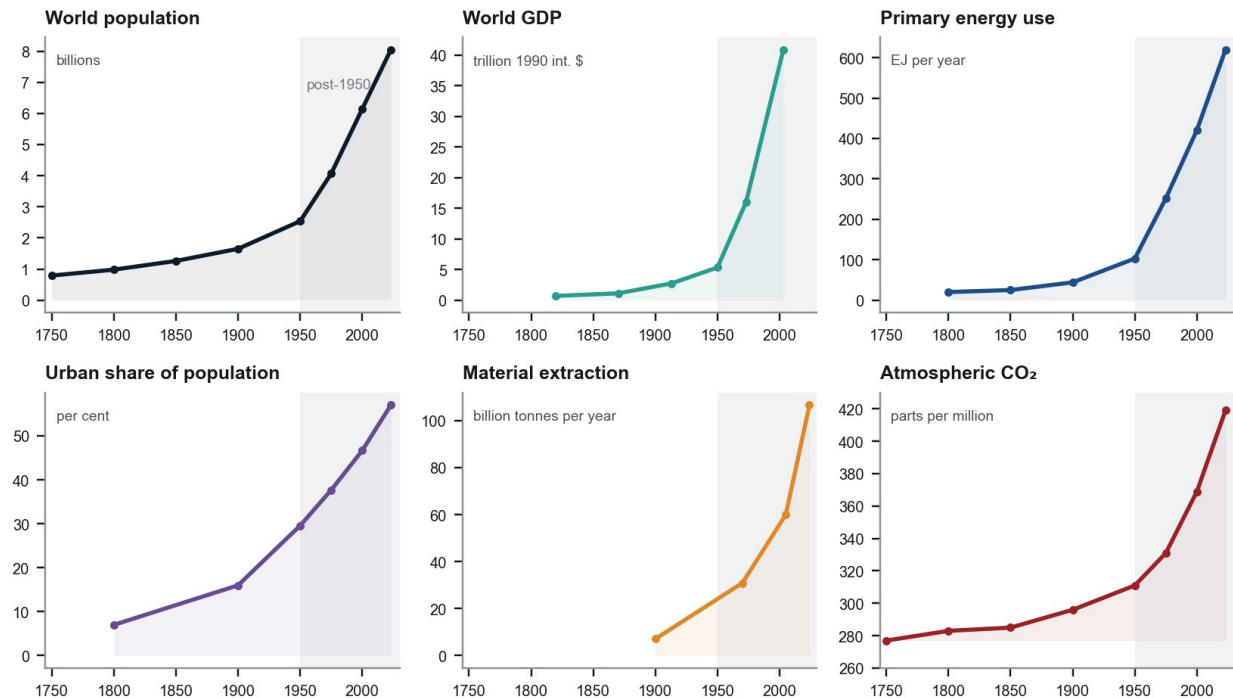


Figure 12. The Great Acceleration. Six indicators of the scale of civilization since 1750. Each grew more steeply after 1950 (shaded) than at any earlier time.

Source: H Heuristics, from [UN](#) and [HYDE](#) population estimates; [Maddison](#) GDP (1990 international dollars); [Our World in Data](#) primary energy; [UN World Urbanization Prospects](#) and earlier estimates; [Krausmann et al. \(2009\)](#) and the UN International Resource Panel for materials; [Ice-core](#) and [NOAA](#) records for CO₂. Values rounded.

The Great Acceleration is the clearest evidence for the productive side of the central hypothesis. Within a single lifetime, civilization's capacity to produce food, goods, energy and information grew several-fold. Life expectancy at birth more than doubled worldwide, from around 30 years in 1800 to [over 70 today](#), and the share of people living in extreme poverty fell from most of humanity to about a tenth. These are real gains, not artifacts of measurement, and any account of civilization's vulnerabilities must begin by acknowledging them.

6.3 Electricity, computing and the information layer

Electricity transformed civilization by separating the production of energy from its use. A generator in one place could drive motors, lights and, later, computers hundreds of kilometers away. The cost was a new kind of dependence. Electrical grids must balance supply and demand continuously, within fractions of a second, across entire continents, and they are tightly coupled to the communication and control systems that manage them. Section 6.7 shows why such coupling makes failure abrupt.

Computing and digital communication did for information what electricity did for energy. [Hilbert and López](#) estimated that between 1986 and 2007 the world's technological capacity to store information grew by about 23 per cent a year, and that by 2007 about 94 per cent of it was digital (Grade A). Since then the growth has continued, and about two-thirds of the world's population [now uses the internet](#). The information layer has become the nervous system of every other layer. Grids, ports, banks, hospitals, supply chains and governments all depend on software and networks. This has made coordination faster and cheaper than ever. It has also created failure modes that did not exist before, from cyberattacks to

software faults. In July 2024 a [single faulty software update](#) disabled millions of computers worldwide and grounded flights, halted hospital systems and interrupted banking for hours.

6.4 Logistics and finance

Two less visible technologies made the global economy possible. The first is modern logistics, above all the standard shipping container. Before [containerization](#), loading and unloading a ship took days of manual labor and theft was common. After the 1960s, containers moved directly between ships, trains and trucks. [Bernhofen, El-Sahli and Kneller](#) estimated that containerization had a larger effect on trade among advanced economies than all trade liberalization agreements combined. [Hummels](#) documented the fall in transport costs that underpinned the second era of globalization (Grade B). More than [80 per cent of the volume of world trade](#) now travels by sea.

The second is finance, which coordinates investment across time and space. Credit lets firms build factories before they earn revenue and lets households smooth consumption. But finance links balance sheets as tightly as logistics links factories. [Schularick and Taylor](#) found that over 140 years, rapid credit growth was the best single predictor of financial crises. [Haldane and May](#) compared banking networks to ecosystems and showed how similarity in banks' strategies, combined with dense interconnection, made the system as a whole fragile even when individual banks appeared sound. [Battiston and colleagues](#) argued that financial regulation needs the tools of complexity science for this reason (Grade B). The 2008 financial crisis began in one segment of the US mortgage market and within months had caused the first fall in world output since the Second World War.

6.5 Cities as engines and as concentrations

Cities are where the productive and the fragile sides of complexity meet most visibly. [Bettencourt and colleagues](#) showed that across urban systems, many socio-economic quantities scale with population as a power law with an exponent above one (Figure 13). New patents, wages, GDP and creative employment grow about 10 to 30 per cent faster than population. Infrastructure such as road surface, cable length and petrol stations scales with an exponent of about 0.8, so larger cities need less per person. Bettencourt later proposed a [theory of these regularities](#) based on the density of social interactions in urban networks (Grade B for the regularities, C for the theory).

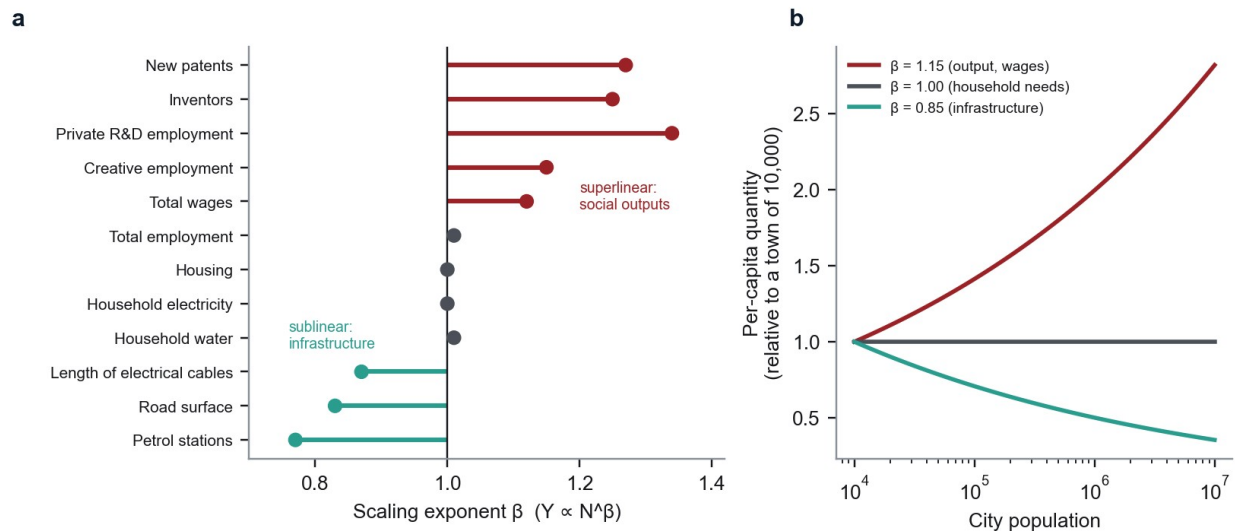


Figure 13. Urban scaling. Published exponents for how urban quantities scale with population in US metropolitan areas (a). Social and economic outputs are superlinear, household needs roughly linear, and infrastructure sublinear. Panel (b) shows what these exponents mean per person: a city ten times larger has about 41 per cent more output per person and needs about 29 per cent less infrastructure per person.

Source: *H Heuristics*, using exponents reported by [Bettencourt et al. \(2007\)](#).

The implications cut both ways. A city ten times larger produces about 41 per cent more output per person and needs about 29 per cent less infrastructure per person. This is why urbanization has driven development, and why [more than half of humanity](#) now lives in cities, a share the UN projects will reach about two-thirds by 2050. But the same studies found that crime and some infectious diseases also scale superlinearly. And concentration means that a single flood, heat wave, earthquake or epidemic can strike a large share of a nation's people and output at once. Cities are civilization's most efficient structures and among its most exposed.

6.6 The anatomy of interdependence

Specialization means that every product depends on many inputs, each of which depends on other inputs, through supply chains that can run to dozens of tiers. Economists have shown that this structure matters for the whole economy. [Acemoglu and colleagues](#) proved that in a production network, shocks to individual firms or sectors need not average out. They can produce aggregate fluctuations when some sectors supply many others. [Carvalho and colleagues](#) traced how the 2011 earthquake and tsunami in northeastern Japan reduced output at firms far from the disaster through their suppliers and customers (Grade A). [Baldwin and Freeman](#) reviewed what is known about risk in global supply chains and found that firms systematically underinvest in resilience relative to what society would choose.

To isolate how the structure of production affects fragility, we built a simple model of a tiered production network (Figure 14). Each product requires K different input types. Each input is bought from r suppliers in the tier below. Raw materials enter at the bottom, and the chain is L tiers deep. Each firm is disrupted directly with a small probability q . A firm that is not disrupted directly still fails if all its suppliers of any one input have failed. We compute the loss of final output analytically, and we simulate a finite version in which firms share suppliers.

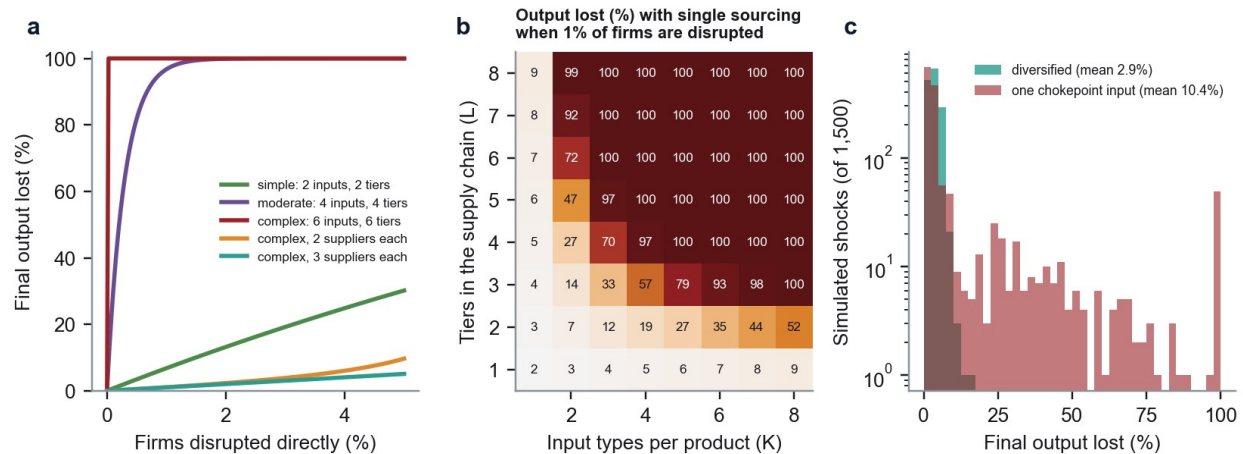


Figure 14. Complexity, redundancy and concentration in production networks. Final output lost as the share of directly disrupted firms rises, for chains of different complexity and redundancy (a). Output lost with single sourcing when 1 per cent of firms are disrupted, as the number of inputs per product and the depth of the chain increase (b). Distribution of losses in 1,500 simulated shocks for a network with four inputs, four tiers and two suppliers per input, when every input has twenty producers and when one input has only two (c).

Source: H Heuristics. Analytic tree model in (a) and (b); finite-network simulation in (c) with 2 per cent direct disruption.

The results show three things.

- 1. Complexity without redundancy is extremely fragile.** With single sourcing and only 1 per cent of firms disrupted, a simple chain with two inputs per product and two tiers loses about 7 per cent of final output. A chain with three inputs and three tiers loses 33 per cent, and one with four inputs and four tiers loses 97 per cent. Every product depends on every firm upstream of it, and the number of upstream firms grows as K^L . This is the O-ring logic of Section 4 applied to whole economies. Real economies are not this fragile, because firms hold inventories, substitute inputs and multi-source. The model shows why those buffers are not optional.
- 2. Modest redundancy restores robustness.** In a complex chain with six inputs and six tiers, single sourcing loses all output when 2 per cent of firms are disrupted. Two suppliers per input cut the loss to about 2 per cent, and three to 2 per cent, close to the floor set by the direct disruption itself. Even at 5 per cent disruption, no more than three suppliers per input were needed to keep losses under 10 per cent for any chain up to eight inputs and eight tiers deep. Redundancy is cheap insurance against complexity.
- 3. Concentration creates fat tails.** In the simulation, a network with two suppliers per input loses on average 2.9 per cent of output, and never more than half in 1,500 shocks. Restricting one input to just two producers worldwide raises the average loss to 10.4 per cent. More importantly, 6 per cent of shocks then destroy more than half of output, and the worst 1 per cent destroy all of it. A chokepoint barely changes the typical outcome and transforms the worst one. This is why concentration risks are easy to miss in normal times.

The model is deliberately stylized, but its lessons match experience. During the COVID-19 pandemic, shortages of semiconductors, which are produced by very few firms in very few places, halted car production worldwide. When the [Ever Given](#) blocked the Suez Canal for six days in March 2021, it held up an estimated 9.6 billion dollars of trade for each day of the blockage. Each case involved a concentrated node in an otherwise redundant system.

6.7 Coupled infrastructure and abrupt failure

Modern infrastructure systems depend on one another. Power stations need communication networks to coordinate, communication networks need electricity, water treatment needs both, and transport needs fuel, power and data. [Buldyrev and colleagues](#) showed that when two networks depend on each other this way, their failure behaves very differently from that of a single network. A single network degrades gradually as nodes are removed. Coupled networks fail abruptly: past a critical point, failures in one network knock out nodes in the other, whose failure knocks out more in the first, until both collapse together. They used the [2003 Italian blackout](#), in which power-station failures disabled internet nodes that in turn disabled more power stations, as a motivating example (Grade A in models, B in data).

We reproduced this result with two random networks of 20,000 nodes, each node having on average four links and each depending on one node in the other network (Figure 15). A single network keeps a connected core until about 70 per cent of its nodes have failed; theory predicts the core vanishes at 75 per cent for infinitely large networks. The coupled pair collapses completely once about 38 per cent of nodes are lost from one network, close to the theoretical 39 per cent. With 40 per cent of nodes knocked out, the single network still has 53 per cent of its nodes connected. The coupled networks have none.

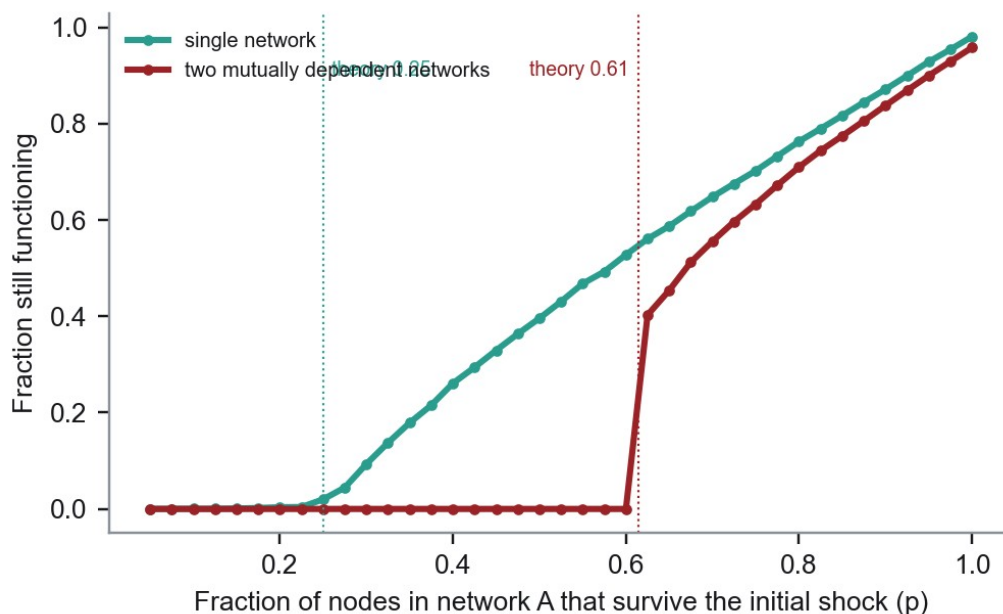


Figure 15. Interdependent networks fail abruptly. The fraction of nodes still functioning in a single random network, and in a pair of networks whose nodes depend on each other, as the share of nodes surviving an initial shock to one network falls. The single network degrades gradually; the coupled pair collapses all at once. Dotted lines mark the theoretical thresholds for infinite networks.

Source: H Heuristics simulation after [Buldyrev et al. \(2010\)](#): two Erdős–Rényi networks of 20,000 nodes with mean degree 4, one-to-one dependency links, averaged over three realizations.

The finding has a disturbing implication for the central hypothesis. Coupling infrastructure systems makes each more efficient in normal times, because they can share data, control and backup. It also converts gradual degradation into sudden collapse and shrinks the margin of safety, without any visible sign until the threshold is crossed. Abrupt failure of this kind is a property of how systems are connected, not of any single component. It cannot be detected by inspecting components one at a time.

6.8 Diminishing returns at the frontier

One further feature of modern complexity bears on the race between production and management. Producing new knowledge appears to be getting harder. [Bloom and colleagues](#) found that research productivity is falling sharply across many fields. Keeping chip density doubling every two years now requires about eighteen times as many researchers as in the early 1970s. [Jones](#) documented a rising *burden of knowledge*: inventors are older at their first invention, more specialized and work in larger teams. And [Park, Leahey and Funk](#) found that scientific papers and patents have become steadily less disruptive (Grade B).

These findings resemble Tainter's argument about diminishing returns to complexity, discussed in Section 9. They do not mean that innovation is ending; total research effort has grown fast enough to keep productivity rising. They do mean that sustaining progress requires an ever larger, more specialized and more interdependent research enterprise. That enterprise is itself a complex system with the vulnerabilities this section describes.

Section finding. Industrialization, electricity, computing, logistics and finance multiplied civilization's productive capacity by creating specialization, connection and scale. The same features create fragility: single-sourced complexity collapses under small disruptions, chokepoints create fat-tailed losses, and coupled infrastructure fails abruptly. Modest redundancy removes most of the fragility, but its benefits are collective and deferred, so markets tend to underprovide it.

07

DIMENSION IV · GLOBAL SYSTEM



7. Dimension IV: The Architecture of Global Civilization

7.1 The question

For most of history there were many civilizations, connected by trade and conflict but largely independent. A drought in the Andes had no effect on China. Today there is, in an important sense, one civilization: a single system of national economies, international institutions, supply chains, information networks and geopolitical relationships in which a disruption almost anywhere can be felt almost everywhere. This section examines how these components combine into a global system that is partially integrated but very uneven. It also asks what that combination means for the system's ability to absorb shocks.

7.2 Two waves of integration

Global integration has not been continuous (Figure 16). A first wave of globalization, carried by steamships, railways, the telegraph and the gold standard, raised world merchandise exports from about 1 per cent of world GDP in 1820 to about 8 per cent by 1913. Two world wars and the Great Depression reversed much of that integration. By 1950, exports had fallen back to about 5.5 per cent of world output. A second wave, built on the post-war institutions, containerization and later the integration of China and the former Soviet bloc, carried the share to about 17 per cent by the late 1990s. The information layer followed even faster. Internet use rose from under 1 per cent of the world's population in 1995 to about two-thirds in 2024.

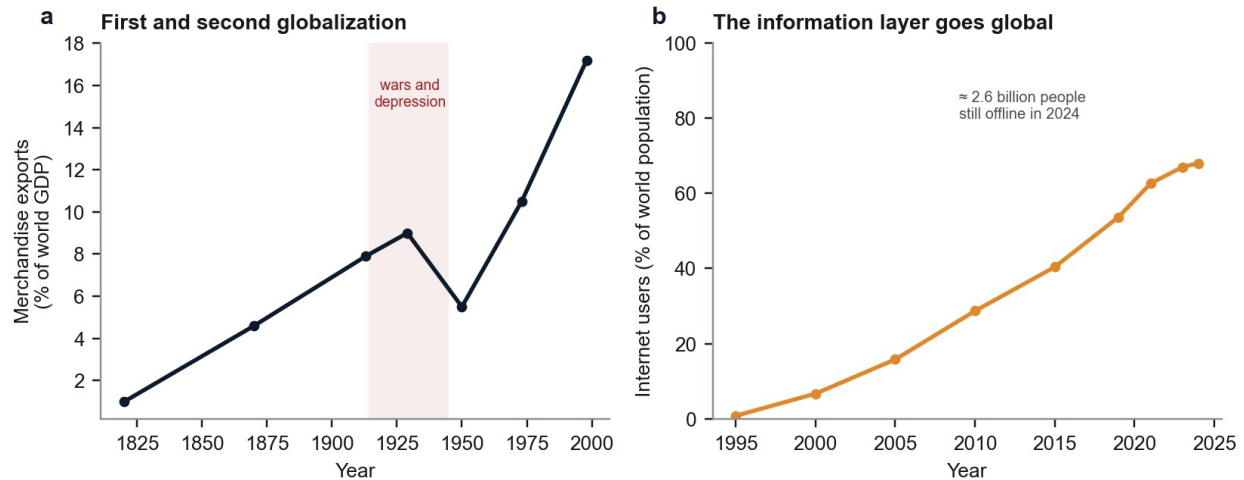


Figure 16. Two waves of integration. Merchandise exports as a share of world GDP, showing the first globalization, its reversal between 1914 and 1945, and the second globalization (a). The share of the world's population using the internet (b).

Source: H Heuristics, from [Maddison](#) (exports at 1990 prices) and the [International Telecommunication Union](#). Values rounded.

The reversal after 1914 is the most important lesson of this history for the framework. Integration is a choice sustained by institutions, technology and political will, and it can be undone. The first globalization was widely believed to have made major war irrational and therefore unlikely. It ended in the most destructive war in history to that date.

7.3 Nation-states and national economies

The basic political unit of global civilization is the nation-state. There are 193 members of the United Nations, ranging in population from about ten thousand to over 1.4 billion and in output per person by more than a hundredfold. Most fiscal capacity, law, infrastructure planning and social insurance still operate at national scale. National states are therefore where most of civilization's adaptive capacity lives, and their uneven capacity is one of the main features of the global architecture.

Whether poorer countries are catching up has been debated for decades. [Pritchett](#) showed that between 1870 and 1990 the gap between the richest and poorest countries widened enormously, a pattern he called *divergence, big time*. [Johnson and Papageorgiou](#) reviewed the evidence and found no general tendency for poor countries to catch up over the post-war period, although middle-income countries in East Asia and elsewhere converged rapidly. [Kremer, Willis and You](#) found that since about 2000 a modest trend toward absolute convergence has emerged, as policies and institutions in poorer countries have improved (Grade B). The H Heuristics report [The Architecture of Creation and Development](#) treats this question in detail. For this report the point is that the global system contains components developing at very different speeds, which shapes how shocks spread and who can absorb them.

7.4 International institutions

Above the nation-state sits a thinner layer of international institutions. Some are old and technical, such as the International Telecommunication Union, founded in 1865 to coordinate telegraph standards, and the Universal Postal Union. Others were created after the Second World War to prevent a repeat of the interwar collapse of trade and cooperation. They include the United Nations, the [Bretton Woods](#)

institutions (the International Monetary Fund and the World Bank), and the General Agreement on Tariffs and Trade, which became the World Trade Organization in 1995.

These institutions have real achievements. The [Montreal Protocol](#) phased out ozone-depleting chemicals and is putting the ozone layer on track to recover by around the middle of the century. International health regulations, aviation safety standards, the law of the sea and financial-stability arrangements coordinate the behavior of nearly every country. But international institutions have little independent fiscal capacity, rely on the consent of member states and are weakest exactly where global risks are greatest: in governing the climate, managing pandemics, regulating new technologies and preventing war between major powers. In the terms of the framework, the institutional layer of global civilization is far less developed than its economic and information layers.

7.5 Supply chains and their concentrations

Production is now organized in global value chains, in which the stages of making a product are spread across several countries. The World Bank's [World Development Report 2020](#) estimated that about half of world trade involves such chains. They raise productivity by letting each stage be performed where it is cheapest. They also build the network structure modeled in Section 6.6 into the global economy, including its chokepoints (Table 7).

Table 7. Selected concentrations and chokepoints in the global architecture

Node	Layer	Concentration	What depends on it
Strait of Hormuz	Energy	About a fifth of global oil consumption passes through it (EIA)	Oil and gas supply to Asia and Europe; fuel prices worldwide
Suez Canal and Red Sea	Economy	Roughly 12 to 15 per cent of world trade by volume before 2024 disruptions	Europe–Asia shipping; container freight rates
Advanced semiconductor fabrication	Technology	Over 90 per cent of leading-edge logic capacity in Taiwan in 2020–21 (SIA and BCG)	Computing, communications, vehicles, defense, AI
Critical-mineral processing	Resources	One country refines most of the world's rare earths, graphite and several battery metals (IEA)	Electric vehicles, renewables, electronics
Breadbasket regions	Resources	A handful of exporters supply most traded wheat, maize, rice and soybeans	Food import dependence of about a quarter of food consumed
Submarine cables and cloud platforms	Information	Most intercontinental data travels on a few hundred cables; a few providers host much of the world's computing	Finance, commerce, government, communication
Reserve currency and payment systems	Institutions	The US dollar is used in most international transactions and reserves	Trade finance; sovereign debt; sanctions exposure

Source: H Heuristics compilation from the sources linked. Shares are approximate and change over time.

These concentrations are not accidents or failures of planning. They result from the same economies of scale and cumulative advantage that produce urban hierarchies in Section 5. A producer that is slightly better or larger attracts more customers, invests more and becomes better still, until it dominates. The efficiency gains are real. So, as the cascade model showed, is the tail risk.

7.6 Information networks and geopolitics

The information layer of global civilization is the most integrated of all. Ideas, prices, news and rumors cross the world in seconds. This has enabled extraordinary coordination, from global scientific collaboration to the rapid sequencing and sharing of the SARS-CoV-2 genome in January 2020. It has also created a new vulnerability in the social-coordination layer. [Vosoughi, Roy and Aral](#) found that on Twitter, false news spread farther, faster and more broadly than true news, largely because people shared it (Grade B). [Lazer and colleagues](#) described the science of misinformation as a new field needed to protect the information ecosystem. A civilization whose coordination depends on shared information is exposed when that information can be cheaply corrupted.

Geopolitics is the layer in which the global system is least integrated and most likely to fragment. After the Cold War, the major powers were bound together by trade and finance to an unprecedented degree. Since the late 2010s, trade restrictions, sanctions, export controls on technology and investment screening have multiplied, and international institutions have struggled to reach agreement. Organized violence has also risen. The [Uppsala Conflict Data Program](#) records more state-based armed conflicts in recent years than at any time since the Second World War. Fragmentation would reduce the efficiency gains of integration without necessarily reducing its risks, since a world of rival blocs would still share one atmosphere, one set of pathogens and one interconnected financial system.

7.7 Integration as insurance, and its limits

One of the most important functions of global integration is insurance. A region that suffers a poor harvest can import food from regions that did not. About [a quarter of the food produced for human consumption](#) is traded internationally (Grade A). Before integrated markets, regional harvest failure meant famine. Since the mid-twentieth century, death rates from famine have [fallen dramatically](#), and today's famines are usually caused by war or political failure rather than by a lack of food in the world.

We modeled the insurance value of trade with a simple calculation (Figure 17). Each region's harvest varies randomly around its average, with a standard deviation of 12 per cent. An isolated region has about an 11 per cent chance each year of a shortfall of 15 per cent or more. If regions pool their harvests through trade, the chance that the pooled supply falls short by that much depends on how many regions take part and on how correlated their harvests are. When shocks are independent, pooling twenty regions makes a 15 per cent shortfall effectively impossible. When they are moderately correlated, at $p = 0.5$, the risk falls only to about 4 per cent. When they are highly correlated, at $p = 0.8$, it is about 8 per cent, barely better than isolation.

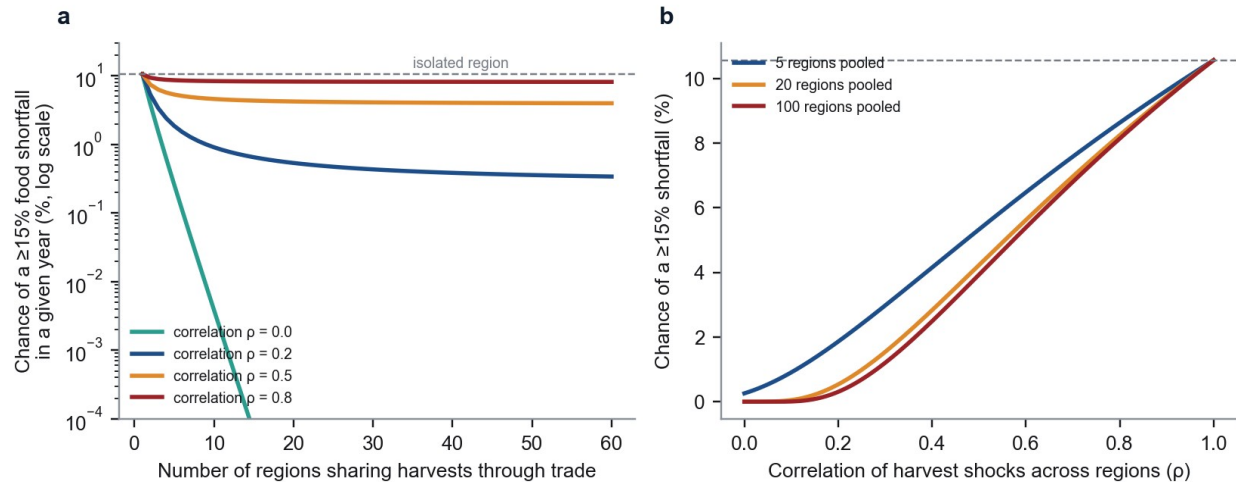


Figure 17. Trade as insurance. The annual chance of a food shortfall of 15 per cent or more for a region whose harvest is pooled with others through trade, by number of regions and the correlation of their harvest shocks (a). Pooling all but eliminates risk when shocks are independent and helps little when they are correlated (b). The dashed line is the risk for an isolated region.

Source: H Heuristics calculation. Harvests normally distributed with a standard deviation of 12 per cent; perfect pooling assumed.

The calculation shows the double edge of global integration. Integration is extremely effective insurance against local, independent shocks, which were the main threat to food security for most of history. It is much less effective against shocks that strike many regions at once. Climate change is raising the probability of exactly such shocks. [Gaupp and colleagues](#) found that the risk of simultaneous crop failures across major breadbaskets has risen with warming, and [Puma and colleagues](#) found that the global food trade network has become more connected and more exposed to the failure of key exporters (Grade B). Integration also transmits shocks. When major exporters restricted grain sales in 2008 and 2010, world prices spiked and import-dependent countries suffered.

7.8 A partially integrated, uneven system

Global civilization is therefore neither a unified system nor a collection of independent ones. Its economic and information layers are deeply integrated. Its institutional layer is thin, and its geopolitical layer is fragmenting. Its components differ more than tenfold in energy use, income and adaptive capacity. This combination may be the most vulnerable configuration possible. Integration is deep enough for shocks to spread globally, but governance is too weak to manage global risks collectively, and the capacity to absorb shocks is concentrated in a minority of countries.

Section finding. Global civilization is deeply integrated in its economic and information layers but thinly governed and increasingly fragmented in its institutional and geopolitical layers. Integration insures against local shocks but transmits global ones, and the concentrations that integration produces create fat-tailed risks.

08

DIMENSION V · VULNERABILITIES



8. Dimension V: Civilization's Vulnerabilities

8.1 The question

Every layer of civilization can fail, and failure in one can spread to others. This section examines seven major sources of vulnerability: climate change, pollution, resource stress, conflict, institutional weakness, inequality and technological hazards. It asks how they interact. The key question, set out in the introduction, is whether complexity increases adaptive capacity faster than it increases systemic exposure. The evidence assembled here suggests the answer has changed over time, and may be changing now.

8.2 The planetary foundation

Civilization grew up in the unusually stable climate of the Holocene, and it depends on the continued functioning of Earth systems it did not create. [Rockström and colleagues](#) proposed nine *planetary boundaries* defining a safe operating space for humanity, and the framework was [updated in 2015](#). The [2023 assessment](#) found six of the nine boundaries transgressed. The [2025 Planetary Health Check](#) added ocean acidification, making seven (Figure 18). The boundaries are not tipping points, and crossing one does not mean immediate catastrophe. They mark the point beyond which the risk of large-scale, possibly irreversible change rises significantly (Grade B).

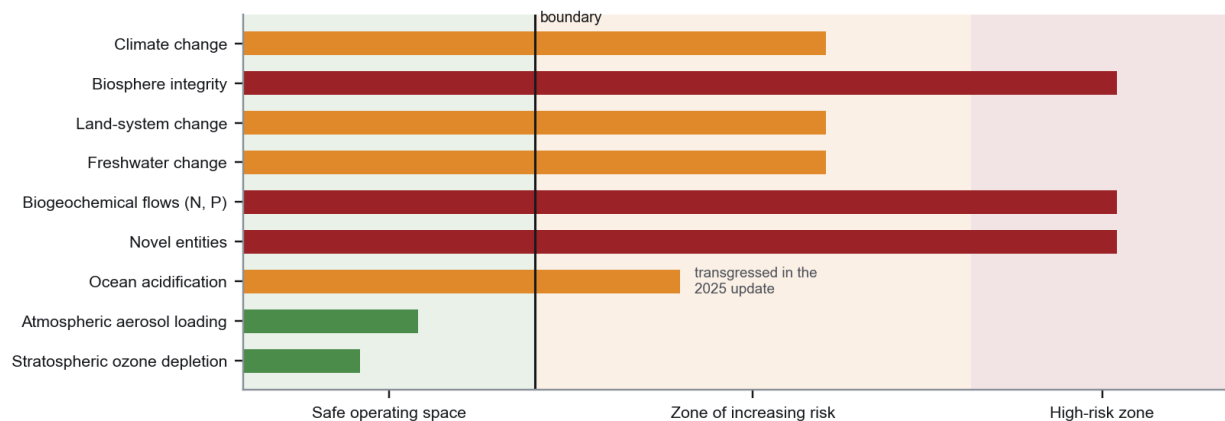


Figure 18. The status of the nine planetary boundaries. Seven of the nine processes that regulate the stability of the Earth system are assessed to be beyond their safe boundaries, several of them in the high-risk zone. Only atmospheric aerosol loading and stratospheric ozone remain within the safe operating space. Bar lengths indicate status category only.

Source: H Heuristics, after [Richardson et al. \(2023\)](#) and the [Planetary Health Check 2025](#). Schematic.

The H Heuristics report [The Architecture of Earth](#) describes how the Earth system's rock, air, water and life are coupled by feedback. In the terms of this report, the planetary boundaries describe the resource layer's limits on everything above it. They are the most fundamental constraint on civilization, and the one civilization is currently pressing hardest.

8.3 Climate change

Global average temperature in 2024 was about [1.55°C above the pre-industrial level](#), the first calendar year above 1.5°C. The long-term warming trend, which averages out year-to-year variation, stands at about 1.3 to 1.4°C (Grade A). The [IPCC](#) has documented widespread effects on heat extremes, heavy rainfall, drought, sea level and ecosystems, with the poorest people and countries the most exposed. Climate change acts on civilization through several layers at once. It reduces crop yields and labor productivity: [Burke, Hsiang and Miguel](#) found that economic productivity peaks at an annual average temperature of about 13°C and declines steeply at higher temperatures. It damages infrastructure and stresses water systems. And it raises the risk of conflict: a [meta-analysis](#) found that each standard-deviation rise in temperature increases the frequency of intergroup conflict by about 14 per cent (Grade B).

The greatest concern is not the average change but the possibility of crossing thresholds. [Armstrong McKay and colleagues](#) found that several climate tipping elements, including the Greenland and West Antarctic ice sheets and tropical coral reefs, may be triggered at warming of 1.5°C or less (Grade B). [Xu and colleagues](#) estimated that under high emissions, one to three billion people could find themselves outside the climate conditions in which humans have lived for the past 6,000 years within fifty years. [Kemp and colleagues](#) argued that catastrophic climate scenarios, including those in which climate change triggers cascading societal failures, are dangerously underexplored (Grade C for the scenarios, A for the call to study them).

8.4 Pollution and resource stress

Pollution is the least discussed of civilization's major vulnerabilities and one of the most deadly. The Lancet Commission on Pollution and Health and its [2022 update](#) estimated that pollution of air, water and soil causes about nine million premature deaths a year, about one in six of all deaths worldwide (Grade B). Air pollution from burning fossil fuels and biomass accounts for most of them. Unlike climate change, much of this harm is immediate and local, and its reduction brings immediate benefits. It is a case where reducing damage to the resource layer directly raises welfare in the layers above.

Resource stress takes many forms. Groundwater is being depleted in several major food-producing regions. Soils are eroding faster than they form on much of the world's farmland. Fisheries have been overexploited, and biodiversity loss is eroding the ecosystem services on which agriculture depends. The energy transition is shifting demand toward copper, lithium, nickel and rare earths, whose supply is geographically concentrated. Resource stress rarely causes collapse on its own. It narrows the margins within which other shocks must be absorbed.

8.5 Conflict, institutional weakness and inequality

Conflict destroys every layer at once. It wrecks infrastructure, disrupts production and trade, displaces populations, diverts resources from investment to destruction, and corrodes trust and institutions. It is also the most direct route by which civilization could destroy itself. Nuclear arsenals remain large enough to

cause a global catastrophe, including through the climatic effects of large-scale nuclear war. Organized violence has risen over the past decade, and great-power competition has intensified.

Institutional weakness is less dramatic but more pervasive. Adaptive capacity, the ability to detect problems, mobilize resources and change course, lives mainly in institutions: public health agencies, central banks, courts, statistical offices, emergency services and legislatures. Where institutions are weak, captured or distrusted, shocks that a capable state would absorb become crises. The difference between societies with high and low state capacity in their response to the same shock, whether an earthquake, a pandemic or a financial crisis, is one of the most consistent findings of the disaster literature (Grade B).

Inequality interacts with both. Long-run data show that [inequality of income and wealth](#) has risen within many countries since about 1980, after falling for much of the twentieth century (Grade A). High inequality concentrates exposure among those with the least capacity to absorb shocks. It can also undermine the social trust and perceived legitimacy on which coordination depends. Structural-demographic theory treats rising inequality and competition among elites as central drivers of the instability phase of secular cycles (Section 9). This is a contested claim, but one with growing quantitative support (Grade C).

8.6 Technological hazards

Civilization's growing power has created hazards that did not exist before the twentieth century: nuclear weapons, engineered pathogens, systemic cyber failure and, potentially, advanced artificial intelligence systems that are not reliably aligned with human interests. [Bostrom](#) argued that risks threatening humanity's long-term potential deserve a priority far greater than their probability alone suggests. [Avin and colleagues](#) proposed classifying global catastrophic risks by how they spread through critical systems and how they defeat mitigation, not just by their initial cause (Grade C). Technological hazards differ from the other vulnerabilities in one important respect. They grow directly out of civilization's capacity to produce complexity, and their potential scale is set by that capacity. They are the purest case of the complexity gap.

8.7 How vulnerabilities interact

Vulnerabilities rarely arrive alone. A drought raises food prices, which fuels unrest, which weakens institutions, which reduces capacity to manage the next drought. Researchers have described this pattern as [compound, interconnected and cascading risk](#), as [compound climate events](#), and, at the largest scale, as a [global polycrisis](#) in which crises are causally entangled. To make these interactions explicit, we assessed how strongly each of the seven vulnerabilities amplifies each of the others, on a scale from 0 (no or weak effect) to 3 (very strong), based on the literature reviewed in this section (Figure 19).

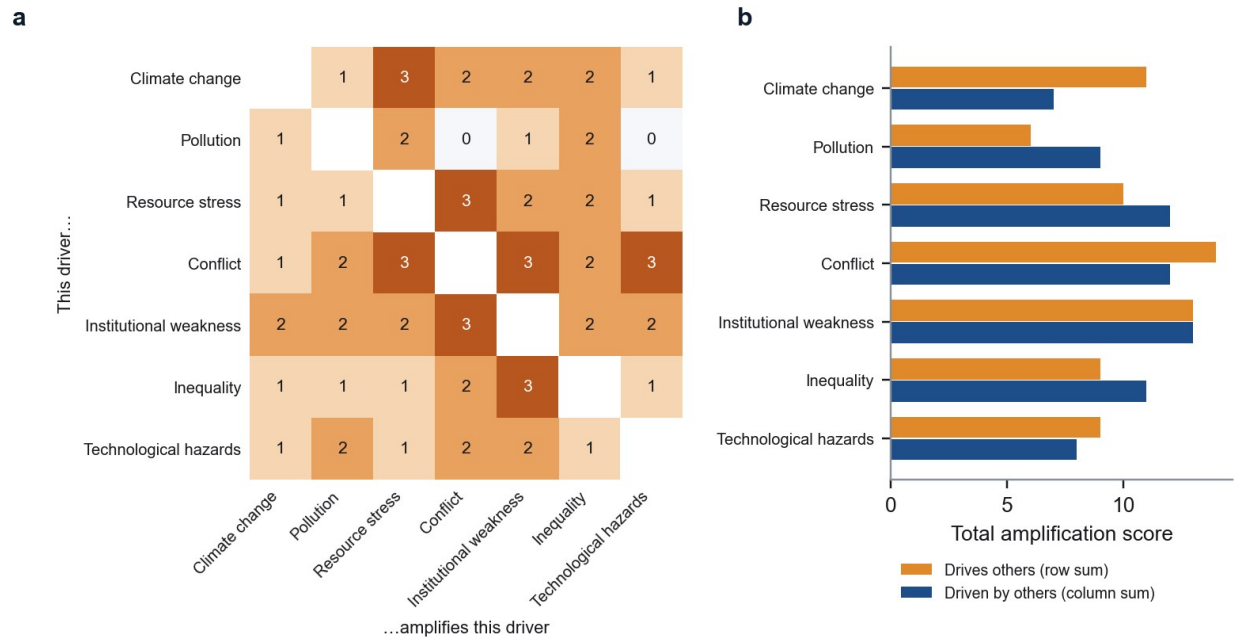


Figure 19. How civilization's vulnerabilities amplify one another. Each cell shows the assessed strength with which the driver in the row amplifies the driver in the column, from 0 to 3 (a). Row and column sums show which vulnerabilities mainly drive others and which are mainly driven (b).

Source: H Heuristics assessment based on the literature reviewed in Section 8. Scores are expert judgments for comparison, not measurements.

Two features stand out. Institutional weakness is the most connected node, scoring 13 both as a driver and as something driven by others. It is the hub through which most other vulnerabilities pass. Conflict is the strongest amplifier, with a total of 14. Climate change scores relatively low as something driven by others but high as a driver (11). It is the most important *exogenous* stress, acting through resource stress, conflict, institutions and inequality. Resource stress and conflict are the most amplified, each scoring 12. These scores are judgments, not measurements, and other assessors would score some cells differently. But the structure, with institutions at the center, is robust to reasonable changes in individual scores. It points to institutional capacity as the most valuable place to intervene.

Table 8. Civilization's seven major vulnerabilities: mechanism, speed and principal interactions

Vulnerability	Main layers affected	Speed	Principal amplifying links	Grade
Climate change	Resources; energy; economy	Slow stress with fast extremes	Resource stress; conflict; institutional strain; inequality	A / B
Pollution	Resources; social coordination (health)	Chronic	Health burden; resource degradation; inequality	B
Resource stress	Resources; energy	Slow, with price shocks	Conflict; institutional strain; inequality	B
Conflict	All layers	Fast	Resource destruction; institutional collapse; technological hazard	A
Institutional weakness	Institutions; social coordination	Slow erosion, fast failure	Every other vulnerability, through reduced response capacity	B
Inequality	Social coordination; economy	Slow	Institutional capture; loss of legitimacy; concentrated exposure	B / C
Technological hazards	Technology; information	Potentially very fast	Conflict; institutional strain; cascading infrastructure failure	C

Source: H Heuristics synthesis. Grades refer to the existence and direction of the main mechanisms, not to their future magnitude.

8.8 Does complexity increase adaptive capacity faster than exposure?

The evidence on the key question of this dimension is mixed, and its balance appears to be shifting. On one side, the record of the past century shows enormous gains in adaptive capacity. Deaths from [natural disasters](#) per head of population have fallen dramatically since the early twentieth century. The reasons are better forecasting, construction, emergency response and food distribution. Famine has almost disappeared outside war zones. Vaccines for a new pandemic virus were developed in under a year. Complexity has, in these respects, made civilization much safer for the average person (Grade A).

On the other side, the same century created exposures with no historical precedent. These include climate change at a rate unseen in human history, transgression of most planetary boundaries, financial and supply networks able to spread a local shock worldwide in weeks, and technologies capable of global catastrophe. These exposures are systemic: they affect the whole system at once and cannot be escaped by moving elsewhere. The gains in adaptive capacity have been largest for frequent, local and familiar shocks. The growth in exposure has been largest for rare, global and novel ones. In the terms of the framework, complexity has increased adaptive capacity faster than exposure for the risks civilization knows how to see. It may have done the reverse for the risks it does not (Grade C).

Section finding. Civilization's vulnerabilities are interconnected, with institutional weakness at the hub and climate change as the most important external driver. Complexity has made civilization far safer against frequent, local shocks, while creating new systemic exposures to rare, global ones. Whether adaptive capacity is keeping pace with these new exposures is the central unresolved question.

09

COLLAPSE AND RECOVERY



9. Resilience, Collapse and Recovery

9.1 The question

The five dimensions describe how civilization is built and where it is exposed. This section asks what history shows about how it responds to stress. Why do some societies absorb severe shocks and recover, while others decline for centuries or fragment? The question is the fourth of the report's research questions, and it is where the principles of adaptive capacity and transformation are tested most directly.

9.2 What collapse is, and is not

Joseph Tainter defined [collapse](#) as a rapid, significant loss of an established level of social complexity: fewer specialists, less hierarchy, less trade, less information flow, smaller territories and simpler institutions. The definition is useful because it is measurable and neutral. It says nothing about whether the people involved became better or worse off, and nothing about whether the culture survived. Many collapses in this sense were followed by the survival of most of the population in simpler polities. The Maya, for example, still number in the millions, and Greek speakers persisted through four centuries without writing after the Bronze Age.

The literature has moved away from dramatic narratives of sudden ruin. [Butzer](#) reviewed many cases and concluded that collapse usually resulted from a combination of environmental stress, economic weakness, political failure and social breakdown, mediated by how elites and institutions responded. [Weiss and Bradley](#) emphasized abrupt climate change as a trigger, but most later work treats climate as one stressor among several (Grade B). The cases in Table 9 illustrate this pattern.

Table 9. Selected historical cases of collapse, persistence and recovery

Case	When	Main stresses	Outcome	What mattered
Late Bronze Age eastern Mediterranean	c. 1200–1150 BCE	Drought ; disruption of tightly linked palace trade; invasions and raids; internal revolt	Palace states destroyed; Linear B writing lost in Greece for four centuries	Interdependence of specialized palace economies; few alternative suppliers
Western Roman Empire	3rd–5th centuries CE	Fiscal strain and currency debasement; civil wars; epidemics; migrations and invasions; climatic deterioration	Fragmentation into successor kingdoms; sharp fall in trade and urban size	Fiscal capacity; contrast with the eastern empire, which persisted until 1453
Classic Maya southern lowlands	8th–9th centuries CE	Repeated droughts ; warfare and political instability ; land degradation	Abandonment of many southern cities; northern centers continued	Rigidity of divine kingship; competition among polities
Angkor	14th–15th centuries CE	Megadroughts alternating with floods that damaged the hydraulic network; shifting trade	Capital moved south; Khmer state persisted	Dependence on a single, rigid water infrastructure
Europe after the Black Death	1347–1351 and after	Loss of perhaps a third to a half of the population	Recovery within about two centuries; higher wages; institutional change	Intact institutions and knowledge; land abundance after the shock
Tokugawa Japan's forest crisis	17th–18th centuries	Severe deforestation from construction and fuel demand	National system of forest management; recovery of forests	Central authority able to detect the problem and enforce long-term rules
Western Europe and Japan after 1945	1945–1960s	Destruction of cities, industry and infrastructure	Rapid recovery to above pre-war output	Surviving human capital and institutions; external support (Marshall Plan)

Source: H Heuristics synthesis of the literature linked and cited in Section 9. Causes of each case remain debated.

9.3 Four lessons from the record

- 1. Collapses have several causes.** No well-studied case has a single cause. Climate shocks, in particular, appear as triggers in many cases, but always acting on societies already under fiscal, political or social strain (Grade B).
- 2. Tightly coupled systems fail together.** The Late Bronze Age palace economies were highly specialized and depended on long-distance trade for tin, copper, grain and luxury goods. When several were disrupted at once, the network unraveled. Societies that relied on a single rigid infrastructure, such as Angkor's hydraulic network, were exposed when that infrastructure failed (Grade B). The pattern matches the cascade and interdependence models of Section 6.
- 3. Response matters as much as the shock.** The Black Death killed a larger share of Europe's population than any of the shocks that brought down the Western Roman Empire, yet Europe recovered within about two centuries. Rome's eastern half survived the crises that ended the western half for almost a thousand years. Tokugawa Japan detected a looming ecological crisis and reorganized its forestry before collapse. In each case, the difference lay in institutional capacity to absorb, adapt and enforce (Grade B).

- 4. What survives determines recovery.** Recovery is fastest when human capital, institutions and knowledge survive even if physical capital is destroyed, as in post-1945 Europe and Japan. It is slowest when knowledge networks are broken. Writing disappeared from mainland Greece for about four centuries after the Bronze Age collapse, and many technical skills declined in post-Roman western Europe. This is the collective-brain mechanism of Section 5 operating in reverse (Grade B).

Ice cores add an unusual quantitative perspective. [McConnell and colleagues](#) measured lead pollution from Roman-era silver mining and smelting recorded in Greenland ice. They found that it tracked plagues, wars and imperial expansion closely, falling sharply during the Antonine plague of the second century and not recovering until the early medieval period (Grade A for the record, B for the interpretation). Pollution, in other words, provides a physical record of the rise and fall of economic complexity.

9.4 Diminishing returns to complexity

Tainter's explanation of collapse is economic. Societies solve problems by adding complexity: more administrators, soldiers, infrastructure and regulation. The first investments in complexity have high returns, because they solve the easiest problems first. Later investments have lower returns, and eventually the marginal return falls below the marginal cost. A society in that position is vulnerable. It has committed resources to a level of complexity that no longer pays, so a further shock can leave it unable to sustain its institutions. Simplification then becomes rational even if it is experienced as catastrophe.

We formalized this argument in a minimal model (Figure 20). The benefit of complexity C rises with diminishing returns, as $B(C) = b(1 - e^{-C/c_0})$, while its cost rises in proportion, as mC . The net benefit peaks at an optimal level of complexity given by equation (4). Beyond that point, each further investment costs more than it returns.

$$C^* = c_0 \ln(b / m c_0) \quad (4)$$

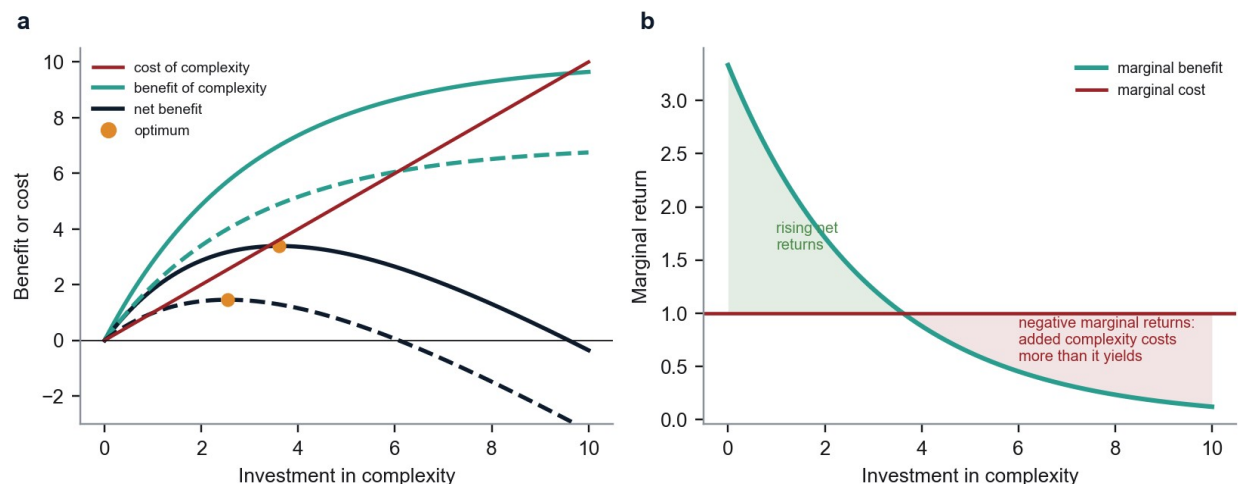


Figure 20. Diminishing returns to complexity, after Tainter. Benefit, cost and net benefit of investment in complexity before and after a 30 per cent fall in the returns to complexity, such as a drought or the loss of a trading partner (a). The optimum (orange) shifts to lower complexity after the shock. The marginal return on complexity falls below its marginal cost beyond the optimum (b).

Source: H Heuristics calculation with $b = 10$, $c_0 = 3$ and $m = 1$. Stylized.

With the parameters used here, a 30 per cent fall in the returns to complexity cuts the net benefit of the optimal level of complexity by 57 per cent and reduces the optimal level of complexity itself by 30 per cent. A society that keeps its former level of complexity after the shock loses 62 per cent of its net benefit.

If returns fall by more than 70 per cent, so that $b < mc_0$, there is no level of complexity that pays at all, and full simplification is the best available response. The model illustrates two of Tainter's claims. A shock to the returns on complexity hurts more when complexity cannot be adjusted. And beyond a certain point, the rational response to falling returns is to shed complexity. A further implication is that societies whose institutions can scale down in an orderly way, rather than breaking, lose less (Grade C as a general theory of collapse; the arithmetic is exact).

The Western Roman Empire's third-century crisis is often cited as an example. Facing simultaneous threats on several frontiers, the empire expanded its army and administration and paid for them partly by debasing its silver coinage, which by the 270s contained only a few per cent of silver. Inflation followed, and the state increasingly collected taxes in kind and tied workers to their occupations. Complexity was maintained by extracting more from a base that was not growing. Whether this proves Tainter's general theory is debated. The sequence of rising costs, falling returns and growing rigidity is well documented.

9.5 Secular cycles

Peter Turchin and Sergey Nefedov's [Secular Cycles](#) documented recurring cycles of two to three centuries in the agrarian states of medieval and early modern Europe and Russia. In each, population growth was followed by stagnation, crisis and recovery. Their *demographic-fiscal* model offers a mechanism (Figure 21). Population grows toward a carrying capacity that depends partly on the state, because a solvent state can maintain order, irrigation and infrastructure. As population approaches the limit, the surplus per person shrinks, state revenues fall below expenditures and the treasury empties. A bankrupt state cannot maintain order, so instability rises and population falls. When population has fallen far enough, the surplus returns, the state recovers and the cycle begins again.

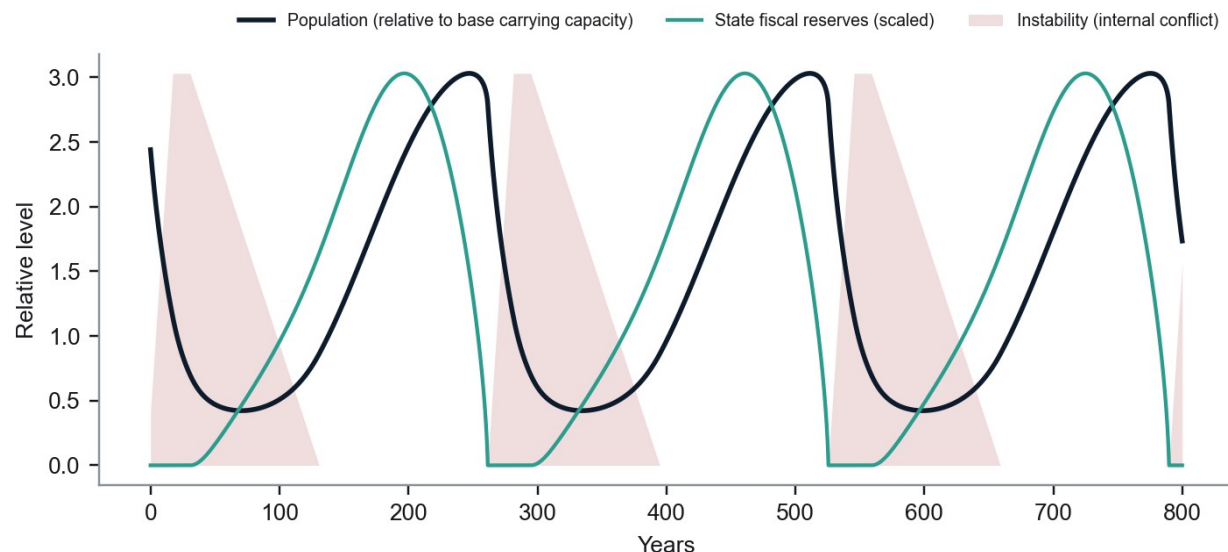


Figure 21. Secular cycles in a demographic-fiscal model. Population, state fiscal reserves and internal instability over 800 years. Population growth erodes the surplus, the state's reserves are exhausted, instability rises and population falls, after which the state recovers and the cycle repeats.

Source: H Heuristics simulation of a demographic-fiscal model after Turchin (2003), with instability rising while the state is insolvent. Units are relative.

Our version of the model produces regular cycles with a period of about 260 years, in which population swings between about 0.4 and 3 times the carrying capacity without a functioning state. The period lies

within the two to three centuries Turchin and Nefedov found in the historical record. The model is not a prediction that modern societies will follow the same rhythm. Their energy base, demography and institutions differ profoundly. Its value for the framework is to show how a society's success in growing can create, through entirely internal dynamics, the conditions for its crisis. Growth erodes the margin per person on which the institutions that sustain growth depend (Grade C as a description of history; the internal dynamic is a mathematical property of the model).

9.6 Recovery and adaptive capacity

The record suggests that adaptive capacity separates societies that recover from those that do not. To isolate this effect, we built a model in which a society's functioning, measured from zero to one, recovers after each shock at a rate that depends on its adaptive capacity (Figure 22). Below a threshold, functioning collapses toward zero instead of recovering. This represents the point at which institutions break down faster than they can be repaired. Higher adaptive capacity both speeds recovery and lowers the threshold, enlarging the range of shocks that can be absorbed. Shocks arrive at random times and remove 20 to 60 per cent of functioning.

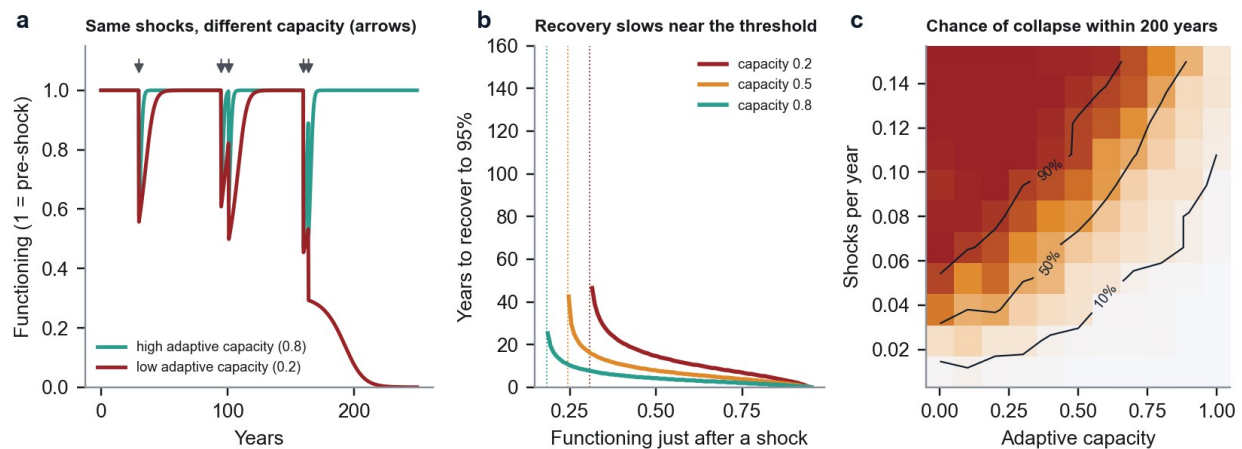


Figure 22. Adaptive capacity and recovery. Two societies hit by the same sequence of shocks (arrows): the one with high adaptive capacity recovers each time; the one with low capacity collapses when two shocks arrive before it has recovered from the first (a). Recovery time rises steeply as the post-shock state approaches the collapse threshold (dotted lines), a form of critical slowing down (b). The chance of collapse within 200 years depends on both adaptive capacity and the frequency of shocks (c).

Source: H Heuristics. Bistable model $dx/dt = r \times (x/\theta - 1)(1 - x)$, with r and θ depending on adaptive capacity; 60 simulations per cell in (c).

Three results stand out. First, the danger lies in compound shocks. In panel (a), both societies recover from every single shock. The low-capacity society collapses only when a second shock arrives before it has recovered from the first. This matches the historical pattern of collapses following clusters of crises. Second, recovery slows dramatically near the threshold. After a shock that halves its functioning, the high-capacity society recovers in about 4 years and the low-capacity one in about 15. A low-capacity society pushed close to its threshold needs 35 years. Slow recovery is itself a warning sign. It is the [critical slowing down](#) that precedes many transitions in ecological and climate systems (Grade A in models). Third, adaptive capacity changes outcomes completely. With one shock every twenty years on average, a society with no adaptive capacity collapses within 200 years in 86 per cent of simulations, while one with full capacity never does. With a shock every ten years, even moderate capacity is not enough, and collapse occurs 81 per cent of the time.

9.7 The adaptive cycle

Holling's [adaptive cycle](#) connects these models. In the growth phase, a system accumulates resources and connections rapidly. In the conservation phase, it becomes efficient, tightly connected and rigid, holding resources in established structures. In the release phase, a disturbance frees those resources suddenly, and in the reorganization phase they are recombined, sometimes into something new. [Folke](#) and colleagues extended the idea to social-ecological systems, distinguishing resilience, the capacity to absorb disturbance and retain function, from transformability, the capacity to create a fundamentally new system when the old one is untenable (Grade B as a framework; difficult to test quantitatively).

The cases, the Tainter model, the secular-cycle model and the recovery model all describe the same structure. Phases of growth build complexity and connection. That complexity becomes rigid and costly. Exposure accumulates, and a shock or cluster of shocks releases it. What follows depends on what survives and on the capacity to reorganize. The next section asks whether this structure can be captured in a single quantitative model of the central hypothesis.

Section finding. Collapse is usually a loss of complexity caused by several interacting stresses, not the disappearance of a people. Societies with the capacity to detect problems, absorb shocks and reorganize recover from shocks that destroy others. Compound shocks, rigid complexity and the loss of knowledge networks are the main routes from crisis to prolonged decline.

10

TESTING THE COMPLEXITY GAP



10. Testing the Complexity Gap

10.1 The model

Section 3 stated the Civilizational Architecture Hypothesis formally. Here we turn it into a model that can be simulated and solved, to see what it implies. The model is deliberately minimal. It contains only the quantities in the hypothesis and the simplest mechanisms connecting them.

A society's complexity C grows each year at rate g , its rate of producing complexity. Its adaptive capacity A grows at rate h , its rate of building the capacity to manage complexity. Systemic exposure grows faster than complexity, as $E = C^\eta$ with $\eta = 1.5$, reflecting the faster growth of interactions than of components. Shocks arrive at random, on average twice a year, with sizes drawn from a heavy-tailed distribution (a Pareto distribution with exponent 1.6). A shock causes a systemic crisis if its size multiplied by the complexity gap ratio $R = E/A$ exceeds a threshold. Two things happen in a crisis. Complexity falls by 15 per cent, as specialized activities are abandoned or simplified, and adaptive capacity rises by 10 per cent, as the society learns from the crisis and builds new institutions. Both effects are well documented historically. Crises destroy capacity, and they also prompt reforms, from new central banks after financial panics to public health agencies after epidemics.

Table 10. Parameters of the complexity-gap model

Symbol	Meaning	Value	Interpretation
g	Growth rate of complexity (production)	2% a year	Doubling about every 35 years
h	Growth rate of adaptive capacity (management)	1.5%, 3% or 4% a year	Below, equal to or above ηg
η	Exponent linking exposure to complexity	1.5	Interactions grow faster than components
λ	Mean number of shocks per year	2	Most are small
α	Tail exponent of shock sizes	1.6	Heavy-tailed: rare shocks are very large
T	Crisis threshold	30	About one crisis a century at the start
d	Loss of complexity in a crisis	15%	Simplification
ℓ	Gain in adaptive capacity after a crisis	10%	Learning from crisis

Source: H Heuristics. Values are illustrative and chosen to produce historically plausible crisis frequencies; Section 10.4 tests sensitivity.

10.2 Results

The model behaves very differently depending on whether production or management grows faster (Figure 23). When adaptive capacity grows at 1.5 per cent a year, less than the 3 per cent growth of exposure (ηg), the frequency of systemic crises rises from about one per century at the start to a steady

state of about 4.4 per century. Complexity still grows, but in a sawtooth pattern of growth and crisis, and it ends up far below where steady growth would have taken it. When adaptive capacity grows at 3 per cent, matching exposure, the crisis rate stays low and slowly falls, to about 0.3 per century, as learning from occasional crises accumulates. When it grows at 4 per cent, crises disappear after the first century. In both of these cases complexity grows almost without interruption.

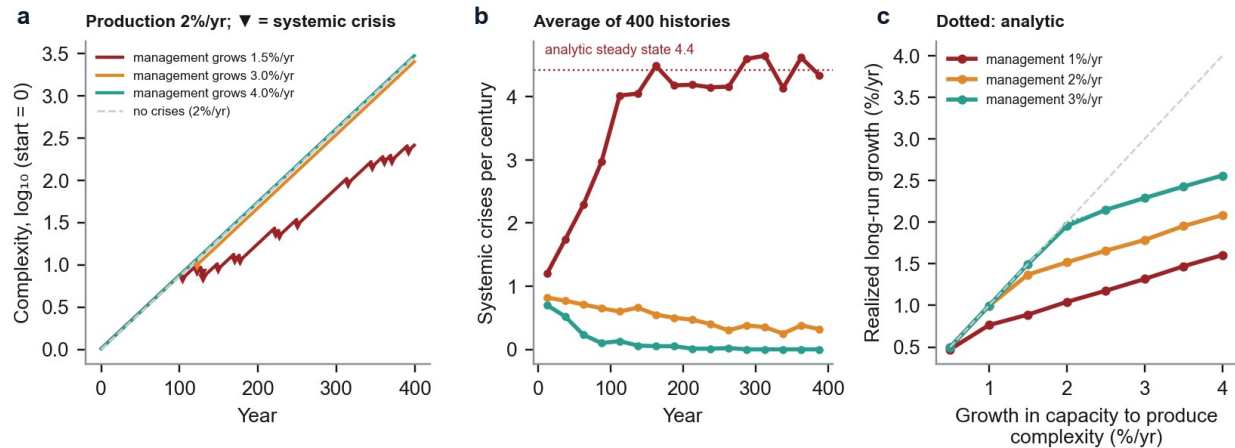


Figure 23. The complexity gap. Complexity over 400 years in three societies with the same 2 per cent annual growth in the capacity to produce complexity but different growth in adaptive capacity; triangles mark systemic crises (a). The average number of crises per century across 400 simulated histories, with the analytic steady state (b). Realized long-run growth of complexity as a function of the growth of productive capacity, for three rates of growth of adaptive capacity; dotted lines show the analytic result (c).

Source: *H Heuristics simulation and analysis of the model described in Section 10.1.*

10.3 Two analytic results

The model can be solved for its long-run behavior, and the solutions match the simulations. When exposure grows faster than adaptive capacity ($\eta g > h$), the complexity gap ratio R would rise without limit if there were no crises. Each crisis reduces it by a fixed factor, $(1 - d)^{\eta/(1 + \ell)}$. In the long run, crises must occur often enough to offset the drift. The steady-state crisis rate κ^* is therefore:

$$\kappa^* = (\eta g - h) / c, \quad c = |\eta \ln(1 - d) - \ln(1 + \ell)| \quad (5)$$

With the values in Table 10, $c = 0.339$, so with $g = 2$ per cent and $h = 1.5$ per cent the steady state is 4.4 crises per century, exactly what the simulation shows. Since each crisis also removes a fraction d of complexity, the realized long-run growth of complexity is:

$$g^* = g - \kappa^* |\ln(1 - d)| = 0.28 g + 0.48 h \quad (6)$$

This is the model's most important result. In a society where production outpaces management, realized growth depends almost twice as much on the growth of adaptive capacity (coefficient 0.48) as on the growth of productive capacity (coefficient 0.28). Doubling the growth of productive capacity from 2 to 4 per cent a year, with adaptive capacity growing at 1 per cent, raises realized growth only from 1.0 to 1.6 per cent. Most of the extra production is lost in more frequent crises. In this regime, the binding constraint on long-run development is management, not production. Panel (c) of Figure 23 shows the simulated and analytic results together. The kink in each curve marks the point where production begins to outpace management, so that crises begin to regulate growth.

10.4 Sensitivity

The two analytic results make it easy to see how the conclusions depend on the parameters (Table 11). Three findings are robust. First, the crisis rate is proportional to the gap $\eta g - h$, so any combination of faster production, more superlinear exposure or slower management raises it. Second, learning from crises (ℓ) reduces both the crisis rate and the growth penalty, so societies that learn more from each crisis need fewer of them. Third, the size of each crisis (d) has a counterintuitive effect. Smaller crises must happen more often to regulate the same gap, but they cost less growth overall. With $d = 5$ per cent, the model produces 8.7 crises per century but realized growth of 1.55 per cent. With $d = 30$ per cent, it produces 2.4 crises per century but realized growth of only 1.15 per cent. Many small corrections are better than a few large ones. This is a formal version of an old argument for allowing small failures, such as small fires, small recessions and small bankruptcies, so that large ones do not build up.

Table 11. Sensitivity of the complexity-gap model: steady-state crises per century and realized growth

Case	Change from base	Crises per century	Realized growth (% a year)
Base case	$g = 2\%$, $h = 1.5\%$, $\eta = 1.5$, $d = 15\%$, $\ell = 10\%$	4.4	1.28
Linear exposure	$\eta = 1.0$	1.9	1.68
Strongly superlinear exposure	$\eta = 2.0$	6.0	1.03
Small, frequent crises	$d = 5\%$	8.7	1.55
Large, rare crises	$d = 30\%$	2.4	1.15
No learning from crises	$\ell = 0$	6.2	1.00
Strong learning from crises	$\ell = 25\%$	3.2	1.48
Faster management	$h = 2.5\%$	1.5	1.76
Faster production	$g = 3\%$	8.9	1.56

Source: *H Heuristics*, from equations (5) and (6). Without crises, realized growth would equal g (2 per cent in all cases except the last, where it would be 3 per cent).

10.5 What the model does and does not show

The model shows that the central hypothesis is internally coherent and has definite consequences. If exposure grows faster than adaptive capacity, crises are not accidents. They are the mechanism by which the gap is regulated, and their long-run frequency is set by the size of the gap. It also shows that adaptive capacity and productive capacity are not interchangeable. In the crisis-regulated regime, a unit of investment in management buys more long-run growth than a unit of investment in production.

The model does not show that today's civilization is in the crisis-regulated regime. That depends on whether ηg currently exceeds h , which requires measuring the growth of exposure and of adaptive capacity. Neither is yet measured well. It also omits many features of real societies. Crises have different sizes and causes, learning can be lost as well as gained, and complexity can be shed gradually rather than in crises. Most importantly, a single global crisis could be large enough to end the process the model describes. The model is a way of thinking clearly about the hypothesis, not a forecast (Grade C for the model as a description of civilization).

10.6 Measuring the gap

Testing the hypothesis empirically requires indicators of both sides of the gap. The report proposes candidate indicators for each (Table 12). Some already exist in fragmentary form. None has yet been assembled into a consistent long-run series.

Table 12. Candidate indicators for measuring the complexity gap

Side of the gap	Quantity	Candidate indicators
Production	Complexity C	Economic complexity indices; number of distinct products and occupations; depth of supply chains; volume of cross-border flows of goods, data and capital
Production	Exposure E	Concentration of critical supply (share of top producer); degree of coupling between infrastructure networks; financial leverage and interconnection; pressure on planetary boundaries; reach of hazardous technologies
Management	Adaptive capacity A	Fiscal space and state capacity; strategic reserves and spare capacity; supplier diversity; early-warning and surveillance coverage; speed of recovery after past shocks; institutional trust
Outcome	Crisis frequency	Frequency and severity of systemic crises across finance, supply, health, climate and conflict, adjusted for reporting

Source: H Heuristics. Indicators are proposals for research; Section 12 states the corresponding hypotheses.

Section finding. A minimal model of the central hypothesis shows that when exposure grows faster than adaptive capacity, crises become the regulator of growth. Their long-run frequency is proportional to the size of the gap, and realized growth then depends almost twice as much on the growth of management capacity as on the growth of productive capacity. Learning from crises and allowing small corrections both reduce the cost.

11

RESEARCH QUESTIONS



11. The Research Questions Revisited

Section 1 posed five research questions that follow from the Civilizational Architecture Hypothesis. This section answers each in turn, drawing on the evidence and models of the preceding sections. Each answer is graded. Table 13 summarizes them.

11.1 Does complexity improve resilience, or create dependencies that exceed institutional capacity?

Both, depending on whether adaptive capacity grows with complexity. Complexity provides the resources for resilience: surpluses, reserves, specialized expertise, transport networks that can move relief, and institutions that can coordinate responses. The century-long decline in deaths from famine and natural disasters shows this capacity at work. But complexity also creates dependence. Single-sourced supply chains collapse under small disruptions (Figure 14), coupled infrastructure fails abruptly (Figure 15), and integration that insures against local shocks transmits correlated ones (Figure 17).

The models suggest a precise answer. Complexity improves resilience when it comes with redundancy, diversity and the capacity to adjust, and it undermines resilience when it is pursued for efficiency alone. A second supplier for each input removes most of the fragility of a complex supply chain. A chokepoint restores the tail risk. In the complexity-gap model, a society's long-run trajectory is set by whether adaptive capacity grows as fast as exposure, not by the level of complexity. Complexity eventually exceeds institutional capacity only if institutional capacity stops growing at the required rate. This has happened repeatedly in history, but it is not inevitable (Grade B for the mechanisms, C for the general claim).

11.2 When does technological progress translate into broad improvements in welfare?

When it diffuses, and when institutions spread its benefits. Diffusion is slow and uneven. [Comin and Hobijn](#) found that across 166 countries and 104 technologies, new technologies reached poorer countries with an average lag of about 45 years, and that differences in adoption explain much of the gap in incomes between countries (Grade A). The H Heuristics report [The Architecture of Creation and Development](#) analyzes the mathematics of this diffusion.

Even where technology spreads, welfare gains are not automatic. During the first decades of the British industrial revolution, output per worker rose while real wages stagnated. [Robert Allen](#) called this *Engels' pause*, and it lasted until about the 1830s or 1840s (Grade B). The large gains in life expectancy of the late nineteenth and twentieth centuries came less from industrial technology itself than from what institutions did with it: clean water, sewerage, vaccination, public education and food regulation. The

general lesson is that technology raises the potential for welfare, and institutions in the coordination and governance layers determine how much of that potential is realized and by whom (Grade B).

11.3 Can societies maintain high complexity while reducing environmental damage and catastrophic risk?

In principle yes, and in some cases they already have. The Montreal Protocol eliminated most ozone-depleting substances without reducing economic complexity. Dozens of countries have reduced their territorial carbon dioxide emissions while their economies grew. The cost of solar electricity fell by about 90 per cent in little more than a decade, according to the [International Renewable Energy Agency](#). Air pollution in many high-income cities is far lower than in the mid-twentieth century. Absolute decoupling of output from environmental damage is possible (Grade A).

Whether it is happening fast enough is another matter. A [systematic review](#) of the evidence found that absolute decoupling of growth from resource use and emissions has been rare, mostly modest and far short of what climate and biodiversity goals require (Grade B). Global emissions have not yet fallen decisively, and material extraction continues to rise. Catastrophic technological risks have, if anything, grown faster than the institutions to govern them. The answer to this question is therefore conditional. High complexity is compatible with low environmental damage and managed catastrophic risk. But reaching that combination requires investment in management capacity, in clean energy, pollution control, monitoring and governance of dangerous technologies, at a pace the world has not yet achieved (Grade C).

11.4 Why do some civilizations recover from severe shocks while others decline or fragment?

The historical cases and the recovery model point to five factors (Grade B).

1. **What survives.** Recovery is fastest when human capital, institutions and knowledge networks survive, even if physical capital is destroyed. It is slowest when the collective brain is broken.
2. **Timing.** Single shocks, even very large ones, are usually survived. Collapse typically follows compound shocks that arrive before recovery from earlier ones is complete.
3. **Distance from the threshold.** Societies already operating near their limits, with fiscal reserves exhausted, legitimacy eroded or surplus per person thin, have little margin. Slow recovery from earlier shocks is a warning sign.
4. **Flexibility of complexity.** Societies whose institutions can scale down in an orderly way, devolving functions, simplifying administration or reorganizing trade, lose less than those whose complexity is rigid and all-or-nothing.
5. **Capacity to learn.** Societies that build new institutions after crises, as the complexity-gap model's learning parameter captures, need fewer crises to stay within their limits.

11.5 Can global civilization develop institutions and infrastructure that let its components converge toward safer, more prosperous conditions?

The evidence supports cautious optimism about convergence, and less about safety. Since about 2000, [poorer countries have on average grown faster](#) than richer ones, reversing more than a century of divergence. Extreme poverty has fallen to about a tenth of the world's population, and life expectancy has

risen in almost every country. Clean technologies are now cheapest in many markets, and latecomers can adopt them without repeating the high-pollution development path of early industrializers.

Convergence toward prosperity is happening, unevenly, as the H Heuristics report [Convergence Before Crisis](#) also documents (Grade B).

Convergence toward safety is less clear. The global architecture described in Section 7 has deep economic and information integration but a thin, fragmenting institutional and geopolitical layer. The risks that most threaten global civilization, including climate change, pandemics, financial contagion, technological catastrophe and great-power war, are exactly those that require global coordination. They are also the ones international institutions are least equipped to manage. The framework's answer is that convergence toward safer conditions is possible, but only if global management capacity grows faster than global exposure. The infrastructure for that, such as monitoring systems, shared reserves, rapid-response finance and agreed rules for dangerous technologies, exists only in fragments today (Grade C).

Table 13. The five research questions: short answers and evidence grades

Question	Short answer	Key evidence	Grade
1. Does complexity improve resilience?	Yes, when adaptive capacity, redundancy and diversity grow with it; no, when complexity is pursued for efficiency alone	Disaster mortality trends; cascade, interdependence and gap models	B / C
2. When does technology raise broad welfare?	When it diffuses and institutions spread its benefits; with long lags otherwise	Adoption lags; Engels' pause; public-health history	B
3. Can complexity coexist with low damage and risk?	In principle and in specific cases; not yet at the necessary pace globally	Montreal Protocol; decoupling reviews; clean-energy costs	A / C
4. Why do some recover and others not?	Survival of knowledge and institutions; timing of shocks; margin; flexibility; learning	Historical cases; recovery model	B
5. Can global civilization converge to safety and prosperity?	Prosperity convergence is underway; safety convergence requires management capacity that does not yet exist	Convergence since 2000; governance gaps	B / C

Source: H Heuristics.

12

HYPOTHESES



12. Hypotheses and Research Agenda

12.1 Ten testable hypotheses

A framework is only as good as the tests it exposes itself to. The report states ten hypotheses that follow from the framework and could be shown false by data that exist or could be collected (Table 14). Each is graded by the current state of evidence. Most are graded C or D, because the purpose of stating them is to invite testing.

Table 14. Ten testable hypotheses

#	Hypothesis	Test	Would be falsified by	Grade
H1	Energy ceiling: a polity's social complexity is bounded above by its energy capture per person	Combine Seshat complexity scores with energy estimates across polities and periods	Highly complex polities with low energy capture	B
H2	Coordination steps: the maximum polity size in a region rises in steps after the adoption of writing, money and bureaucracy	Time-series of maximum polity size against dates of adoption in Seshat	No change in growth of polity size after adoption	C
H3	Collective brain: technological complexity rises with the logarithm of connected population, and falls after isolation	Archaeological tool inventories; isolation events; modern firm and research networks	No relation, or no loss after isolation	B
H4	Superlinear exposure: systemic exposure grows faster than output ($\eta > 1$)	Track concentration, coupling and leverage against output over time	Exposure indicators growing no faster than output	D
H5	Redundancy pays: supply chains with two or three sources per input suffer much smaller losses from comparable shocks, with diminishing returns beyond	Firm-level data from natural disasters and the COVID-19 disruptions	No difference, or continued strong gains beyond three sources	B
H6	Correlated shocks: the food-security benefit of trade falls as cross-regional yield correlation rises	Yield data for major producers; import-dependent food prices	Benefit unchanged as correlation rises	B
H7	Complexity gap: systemic crisis frequency tracks the gap between the growth of exposure and of adaptive capacity	Financial crises against credit growth and supervisory capacity; supply crises against concentration and reserves	No relation between crisis frequency and the gap	C
H8	Learning from crisis: reforms after crises reduce the recurrence of similar crises	Recurrence of banking, epidemic and supply crises before and after major reforms	No reduction in recurrence after reform	C
H9	Slowing recovery: recovery from moderate shocks lengthens before major breakdowns	Recovery times of output, population or state revenue before historical breakdowns	No lengthening before breakdowns	C
H10	Graceful simplification: polities able to devolve and simplify lose less in crises than rigid centralized ones	Seshat and historical records of collapse severity against institutional structure	No difference in severity	D

Source: H Heuristics. Grades reflect the current state of evidence for each hypothesis.

12.2 A research agenda

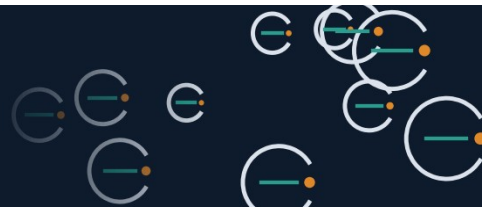
Testing these hypotheses requires five lines of work.

- 1. A complexity gap index.** The most important missing measurement is a consistent long-run index of systemic exposure and adaptive capacity, built from the indicators in Table 12. Without it, hypotheses H4 and H7 cannot be tested and the report's central judgment cannot be confirmed or refuted.
- 2. Linking historical databases.** Seshat and similar databases now code hundreds of past societies. Linking them with estimates of energy capture, climate and trade connectivity would allow H1, H2 and H10 to be tested across the full sweep of history.

3. **Firm-level network data.** Supply-chain shocks of the past fifteen years have produced unusually detailed data on how disruptions spread through production networks. Systematic analysis could test H5 and estimate how much redundancy firms actually hold.
4. **Recovery as a leading indicator.** If recovery slows before breakdowns, as H9 predicts, routine monitoring of recovery times after moderate shocks could provide early warning. This is the human-systems version of the [early-warning signals](#) studied in ecology and climate.
5. **Institutional learning.** Whether crises lead to lasting improvements in adaptive capacity, or whether lessons fade, is central to the long-run trajectory. A comparative study of post-crisis reforms and their durability would test H8.

13

LIMITS OF THE FRAMEWORK



13. The Limits of the Framework

13.1 No predetermined trajectory

The framework identifies recurring mechanisms. It does not predict the future of any civilization, and it should not be read as a theory of inevitable rise and fall. History is full of contingency. Battles might have gone the other way, an epidemic might have arrived a decade later, or a reformer might have died young. The mechanisms in this report change the probabilities of outcomes. They do not fix them. Cyclical theories of history have a long record of confident predictions that did not come true, and the secular-cycle model of Section 9 is offered as an illustration of a mechanism, not a schedule.

A related danger is teleology, the idea that civilization is heading somewhere, such as toward ever greater complexity, unity or progress. The evidence does not support any such direction. Complexity has risen over the last twelve thousand years taken as a whole, but it has fallen in many places for long periods. Nothing in the framework guarantees that it will continue to rise.

13.2 The shape of the evidence

The historical record is biased in ways that can mislead any framework built on it. Literate, monumental and long-lasting societies leave far more evidence than others, so the record overrepresents states and empires and underrepresents the many societies that remained small by choice or circumstance. Collapses are more visible than quiet persistence. Research has concentrated on a few regions, especially the Mediterranean, Western Europe and China. And much of the social-science evidence on modern behavior comes from what [Henrich, Heine and Norenzayan](#) called WEIRD societies: Western, educated, industrialized, rich and democratic. These are unusual by global and historical standards (Grade A that the bias exists).

The report has tried to reduce these biases by drawing on independent centers of civilization across all inhabited continents and by using quantitative databases that code many societies consistently. It cannot remove them. Several of the principles, particularly those about adaptive capacity and recovery, rest on a small number of well-studied cases, and their grades reflect that.

13.3 Measurement

The central variables of the framework, complexity, exposure and adaptive capacity, are hard to measure. Seshat's measures of social complexity are a major advance, but they capture scale and hierarchy better than the density of connections or the depth of dependencies. Adaptive capacity is easiest to see after the fact, in how a society responded to a shock. That creates a risk of circular reasoning, in which societies that recovered are said to have had high adaptive capacity because they recovered. The framework avoids this only if adaptive capacity is measured independently and in advance, through

indicators such as those proposed in Table 12. Until that is done, the central judgment of the report, that global production of complexity is currently outpacing its management, remains graded D.

13.4 Models and analogies

The ten models in this report are deliberately simple. Each isolates one mechanism and leaves out much that matters in reality. The production-network model assumes independent failures and strict requirements for every input; real firms substitute, hold inventories and adapt. The complexity-gap model reduces civilization to two growth rates and a crisis rule. The parameters of every model are illustrative, chosen to produce plausible behavior, not estimated from data. The models are tools for thinking clearly about mechanisms, and their quantitative results should be read as orders of magnitude and directions of effect, not as estimates of real-world values.

The report also borrows concepts from ecology, physics and network science: resilience, critical slowing down, percolation, adaptive cycles. Some of these transfer well because the underlying mathematics is the same. The behavior of interdependent networks near a percolation threshold, for example, does not depend on whether the nodes are power stations or routers. Others are analogies, and the series' [unified report](#) warns that resemblance is weak evidence of shared mechanism. Human societies differ from ecosystems in one crucial respect. Their components can anticipate, deliberate and deliberately change the rules. This makes them both more capable of avoiding crises than any ecosystem and capable of failures, such as war, that ecosystems do not have.

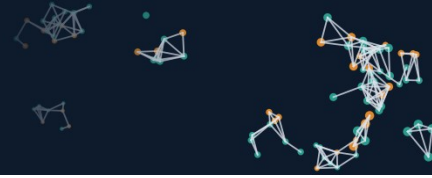
13.5 Values

Finally, the framework is not value-neutral, however much it tries to be. Calling an outcome a collapse, a recovery or a success implies a judgment about what matters. The collapse of a centralized state may have been a liberation for the people it taxed and conscripted. The complexity of modern civilization has delivered enormous gains to some and imposed costs, from colonial extraction to pollution, on others. The report treats complexity as neither good nor bad in itself, and adaptive capacity as valuable because it allows people to pursue whatever they value under changing conditions. Readers who weigh these things differently will draw different conclusions from the same evidence.

What would change the conclusions. The report's central judgment would be weakened if consistent measurements showed that systemic exposure grows no faster than output ($\eta \leq 1$), or that adaptive capacity has grown at least as fast as exposure in recent decades, or that crisis frequency is unrelated to the gap between them.

14

IMPLICATIONS



14. Implications

14.1 From diagnosis to design

If the Civilizational Architecture Hypothesis is broadly right, the most important practical question for any complex system, whether a city, a firm, a supply chain, a nation or the global economy, is not how to grow faster. It is how to grow its capacity to manage complexity at least as fast as it grows complexity itself. The models and evidence of this report translate into ten working heuristics (Table 15). They are offered as rules of thumb for designers, policymakers and researchers, not as a complete program.

Table 15. Ten heuristics for a durable civilization

#	Heuristic	Rationale	Evidence in report
1	Measure both sides of the gap	Production is measured obsessively; exposure and adaptive capacity barely at all. What is not measured is not managed.	Sections 3, 10; Table 12
2	Add redundancy where coupling is tight	A second or third source removes most of the fragility of complex chains at modest cost.	Figure 14
3	Map and reduce chokepoints	Concentration barely changes typical outcomes but transforms worst cases, so it is invisible until it matters.	Figure 14; Table 7
4	Invest in institutional capacity first	Institutions are the hub through which most vulnerabilities interact, and the store of adaptive capacity.	Figure 19; Section 9
5	Prefer many small corrections to few large crises	Small, frequent adjustments regulate the gap at lower long-run cost than rare, severe ones.	Table 11
6	Institutionalize learning from crises	Learning reduces both the frequency and the cost of crises; lessons that fade must be relearned.	Section 10; Table 11
7	Protect the collective brain	Knowledge is a property of large connected networks and is lost when they shrink or fragment.	Figure 11
8	Decouple the energy base from its damage	The energy layer both sustains civilization and drives its largest environmental threat.	Section 4; Section 8
9	Design for graceful simplification	Systems that can scale down in an orderly way lose far less than rigid all-or-nothing ones.	Figure 20; Section 9
10	Govern correlated risks collectively	Integration insures against local shocks but not global ones; correlated risks need shared management.	Figure 17; Section 7

Source: H Heuristics.

14.2 For governments

For governments, the main implication is that resilience is a public good that markets will underprovide. The benefits of redundancy, reserves, early warning and institutional capacity are collective and deferred, so private actors will invest less in them than society would choose. This is the clearest case in the report for public action. It includes strategic reserves of food, fuel and medical supplies; requirements or incentives for supplier diversity in critical sectors; stress tests that model correlated and compound shocks, not just single ones; and sustained investment in the agencies that monitor and respond to risk, especially between crises, when their budgets are most often cut. Governments should also measure and publish indicators of systemic exposure and adaptive capacity alongside the familiar indicators of output.

14.3 For firms and infrastructure operators

For firms, the cascade model offers an encouraging message: most of the fragility of complex supply chains can be removed by modest redundancy, typically a second and sometimes a third source for critical inputs. The difficulty is that concentration risk is invisible in normal times and the cost of redundancy is visible every quarter. Mapping supply chains beyond the first tier, identifying single points of failure several tiers up, and holding buffers proportionate to the depth and complexity of the chain are practical responses. For infrastructure operators, the interdependence result implies that the coupling between power, communications, water and transport systems should be mapped and managed as a system. Independent fallback capacity should be maintained so that a failure in one system cannot take down the others.

14.4 For the international system

For the international system, the most important implication concerns correlated risks. Integration has made civilization far more resilient to local shocks, and that achievement should not be thrown away through fragmentation. But the risks that now matter most, including climate change, pandemics, financial contagion, technological catastrophe and great-power war, are correlated across the whole system and cannot be insured against by trade alone. Managing them requires institutions with the capacity to monitor, coordinate and respond at global scale. The thinness of that institutional layer, relative to the depth of economic and information integration, is in the framework's terms the single largest gap in the architecture of global civilization.

14.5 For the Architecture of Creation series

Within the series, this report extends the framework of constraints, generators and filters to the largest system humans have built. It adds one idea that may apply more widely: that the relative speed of generation and filtering matters as much as either alone. In biological evolution, generation and filtering are roughly matched, because each generation is tested before the next is produced. In civilization, generation can outrun filtering. New technologies, financial instruments and dependencies can be produced faster than their consequences can be tested. When that happens, the filter acts suddenly, as crisis. Whether this asymmetry appears in other creative systems is a question for future work in the series.

15

CONCLUSION



15. Conclusion

15.1 The answer to the central question

This report asked how civilization emerges from individual human activity, organizes itself into increasingly complex systems, and sustains or undermines the conditions required for its continued existence. Its answer has three parts.

Civilization *emerges* when a stable climate, productive crops and accessible energy create a surplus that frees people to specialize. Simple local rules, such as moving to larger places, trading with reliable partners and copying the most skilled, then generate cities, markets and accumulated knowledge that no one designed. This happened independently on several continents within a few thousand years of the start of the Holocene, which shows that civilization is a recurring solution to a recurring set of constraints, not a unique accident.

Civilization *organizes* itself through coordination technologies, from writing, law and money to bureaucracy, markets and digital networks. Each extended cooperation beyond the limits of personal relationships and each made the system more productive and more interdependent. Industrialization and its successors multiplied this process, producing within two centuries a single global system of extraordinary productive capacity, deeply integrated in its economic and information layers and thinly governed in its institutional and geopolitical ones.

Civilization *sustains or undermines* itself according to the relationship between two capacities: to produce complexity and to manage its consequences. When management keeps pace, complexity makes civilization more resilient, as the century-long decline in deaths from famine and disaster shows. When production outpaces management, unmanaged exposure accumulates through concentration, coupling, environmental pressure and dangerous technologies. Crises then become the mechanism that restores the balance, at a cost that rises with the size of the gap.

15.2 The verdict on the hypothesis

The Civilizational Architecture Hypothesis, that civilization's long-term trajectory is shaped by the relationship between its organizational complexity, productive capacity, interdependence and ability to adapt, survives the tests applied in this report. The historical cases are consistent with it. Societies that recovered from severe shocks retained or rebuilt adaptive capacity, and those that declined had exhausted it. The models give it definite form. When exposure grows faster than adaptive capacity, crisis frequency rises in proportion to the gap, and long-run growth comes to depend more on management than on production. The hypothesis is not yet confirmed, because its key quantities have not been measured consistently. The report grades it C overall, with a clear agenda for raising or lowering that grade.

The report's working judgment about the present is graded D. In the twenty-first century, civilization's capacity to produce complexity is growing faster than its capacity to manage the consequences, especially for rare, global and novel risks. If that judgment is right, the most valuable investments available to civilization are not in producing more but in managing better. They include redundancy, reserves, monitoring, institutions, learning, and the governance of correlated risks and dangerous technologies.

15.3 Closing

Civilization was not designed, and no one is in charge of it. It is the accumulated result of billions of decisions, constrained by energy and geography, organized by institutions and information, and filtered by success and failure. That is what makes it remarkable, and also what makes it vulnerable. A system no one designed is a system no one is responsible for maintaining. The history assembled in this report shows that complex societies are neither doomed nor safe. They last when the people within them build the capacity to understand and manage what they have built, as fast as they build it.

Final verdict. Civilization's long-term survival depends less on how much complexity it can produce than on whether its capacity to manage complexity grows as fast. That capacity is buildable, measurable and, for now, underbuilt.

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