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Contingency, Pattern and the S-curve in Human History[1]

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If you study an old-fashioned television screen up close, you'll see dots of different colors dancing in front of your eyes. You'll think you are looking at chaos. But stand back, and you will see a picture full of meaning. Something like this happens over and over again as we study the past. Stand too close to the details and it's hard to see anything but the idiosyncratic actions of individual human beings. Big history helps us stand back from the details and see the patterns. By doing so, it can transform our ideas of what history is about.

Contingency and Pattern in Human History

Most historians study highly contingent processes. On June 28, 1914, a Bosnian Serb, Gavrilo Princip assassinated the heir to the Austrian throne, the Archduke Franz Ferdinand, starting a chain of events that led to the outbreak of World War I. This was an extremely unpredictable event. His gun might have misfired; he might have missed his target; he might have had cold feet; he could have not been born, or been born with a slightly different genetic make-up or … Many things could have changed the course of events. Such contingencies are not confined to human history. The American geologist, Walter Alvarez, proved that the disappearance of most species of dinosaurs about 67 million years ago was due to the landing of an asteroid off the coast of Yucatan, which created the equivalent of a nuclear winter and destroyed most large species on earth. That event cleared the way for the evolution of mammal species, which, until then, had consisted mostly of small, timid shrew-like creatures. If Alvarez' asteroid had been on a trajectory five minutes earlier or later, we would not be here.[2]

Yet so familiar is contingency to historians today, and so powerful is the notion of human agency, that some historians believe history is radically different from the natural sciences. R.G. Collingwood, for example, argued that the natural sciences study regular, law-obeying processes such as the workings of gravity, while historians study the unpredictable actions of conscious, self-aware and freely acting women and men.[3] That was why historians seemed to occupy a different epistemological universe from natural scientists. I suspect most historians still sympathize with Collingwood's argument.[4]

I will argue that these beliefs, which sustain divisions between the humanities and the sciences, are based on a misunderstanding of the relationship between pattern and contingency. The misunderstanding may arise, in part, from a reaction against extreme forms of determinism, which argued that *all of reality was patterned*. The French mathematician, Pierre-Simon Laplace (1749-1827) once wrote that:

> *An intellect which at a certain moment would know all forces that set nature in motion, and all positions of all items of which nature is composed, if this intellect were also vast enough to submit these data to analysis, it would embrace in a single formula the movements of the greatest bodies of the universe and those of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes.*[5]

Laplace's rigid determinism was already untenable by the early twentieth century because the second law of thermodynamics showed that there was a genuine openness or unpredictability about the future. Not all events were time-reversible. Then quantum physics found contingency in the heart of the material world. The behavior of individual sub-atomic particles can never be predicted with perfect accuracy. You cannot tell, for example, when a particular atom of Uranium will undergo radioactive decay. This is not just a matter of experimental practicalities but an intrinsic quality of matter and energy. Reality is fuzzy at small scales. You can never bring it into perfect focus. But contingency is not just present at small scales. I have already mentioned Alvarez' asteroid impact. The French mathematician, Henri Poincaré showed in the nineteenth century that the movements of three or more astronomical bodies linked by gravity are unpredictable. Here tiny differences in the initial conditions seem to get magnified over time. This is the famous "butterfly effect". An even more spectacular example of contingency at very large scales is the (apparently serious) speculation that the entire Universe may be the result of a "quantum fluctuation" at the moment of the big bang.

So modern physicists, like historians, are familiar with contingency. Yet they also know that there are powerful patterns that allow us to establish what we routinely describe as "scientific laws." Are the realms of pattern and contingency really separated by the sort of epistemological chasm between mind and matter that shaped Collingwood's thinking?

In practice, we often find that contingency and pattern seem to flow into each other because most events in both history and the natural world are governed by varying degrees of probability. As a result, contingency seems to give way to pattern and vice versa in subtle and often beautiful ways. Indeed, the same mechanisms that generate apparently random processes at one scale may generate predictable processes at different scales. Two centuries ago, Immanuel Kant already understood that this complex relationship shapes human history as well as the physical world.

> *Whatever concept one may hold … concerning the freedom of the will, certainly its appearances, which are human actions, like every other natural event are determined by universal laws. However obscure their causes, history, which is concerned with narrating these appearances, permits us to hope that if we attend to the play of freedom of the human will in the large, we may be able to discern a regular movement in it, and that what seems complex and chaotic in the single individual may be seen from the standpoint of the human race as a whole to be a steady and progressive though slow evolution of its original endowment.*[6]

Kant illustrated his argument by pointing out what every demographer knows: that the free demographic choices of millions of families result in predictable demographic patterns.

Yet many historians still feel uncomfortable with the idea that patterns shape human history as much as agency and contingency. Colin Renfrew has noted a similar resistance among prehistorians. For most prehistorians, he writes: "The world … is constructed through individual actions by individual people. It is a rich palimpsest, testifying to human creativity, and perhaps little more is to be expected than the collection and collation of regional narratives."[7] And yet, he points out, there clearly are large patterns in prehistory if you look for them, such as the striking similarities between the agrarian civilizations ties that emerged independently in Afro-Eurasia and the Americas. Similarities include pyramid-like monumental architecture, the construction of calendars, the evolution of writing, states, cities and trade and the appearance of a division of labor by gender, class and ethnicity. As Renfrew points out, these odd parallels "must imply some commonality both in practicality and in potential, as both are products of the human condition."[8]

These arguments suggest that resistance to the exploration of large-scale patterns in human history is a mistake, and one that limits the explanatory possibilities for the history discipline as a whole. There are, to put it frankly, aspects of human history that cannot be adequately handled using the familiar mantras of agency and contingency. However, to see these patterns clearly, you need to shift to large scales, scales much larger than Braudel's *longue durée*. Few historians feel comfortable at these large scales, and that may be why historians rarely discuss the large patterns. In the next section, I want to discuss some patterns that can be seen once we shift to the scale of human history as a whole. That is a scale of approximately 100-200,000 years.

The S-Curve

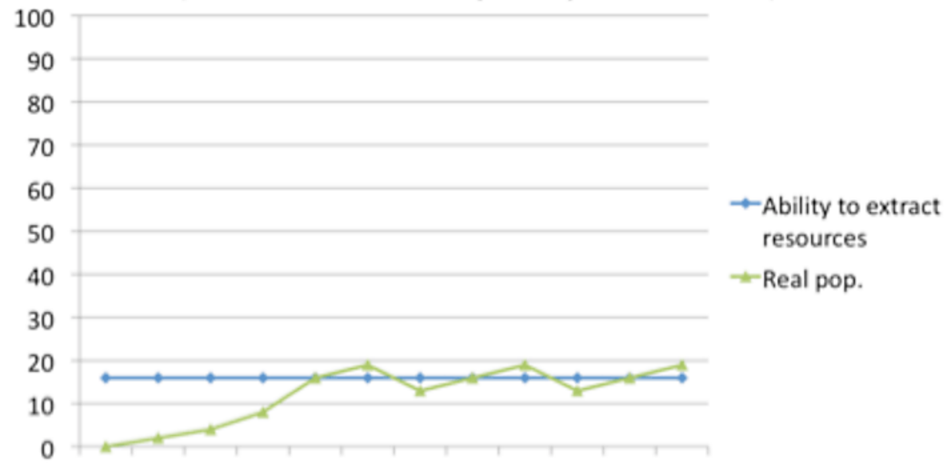
One of the most fundamental and revealing of the large patterns in human history is the "S-curve" describing population growth. The S-curve is a fine example of how the unpredictable behavior of many individuals can yield clear patterns because, with minor modifications, this pattern seems to describe the population histories of all species, from bacteria to chimpanzees.

The "S-curve" or logistic curve, describes a pattern of growth familiar in many fields, from population dynamics to the study of innovation. The idea is ancient. Long before Thomas Malthus wrote his *Essay on the Principle of Population*, Ecclesiastes had written: "When goods increase, they are increased who eat them." Adam Smith wrote in *The Wealth of Nations*: "Every species of animals naturally multiplies in proportion to the means of their subsistence, and no species can ever multiply beyond it."[9] In other words, there is a close relationship between populations and available resources.

The S-curve describes this relationship. When a species is young and exploring the niche to which it is adapted by natural selection, its numbers will grow rapidly because plenty of resources are available. Eventually, though, the species will find it is using all the resources it can extract given its genetic endowment. Then it will settle into a wobbly demographic equilibrium. It will overshoot the available resources, collapse below them, then overshoot them again, creating the indefinitely extended, if shaky, horizontal upper arm of the S-curve. For the rest of its time on earth, members of the species will make minor demographic and ecological adjustments for climatic changes or diseases or other unexpected events. Thousands or even millions of years later, the species will die out or evolve into a new species when climatic change, competition from other species, or some other factor reduce the available resources. But while the species survives we will see little long-term change. If you want to find history in the biological realm you have to move to higher taxonomic levels, to the level of the genus, or family or order, or even to the history of life as a whole, and you have to move to scales of millions of years. Then you can see evolution and change, driven, for the most part, by natural selection. But at the level of the species you do not find history.

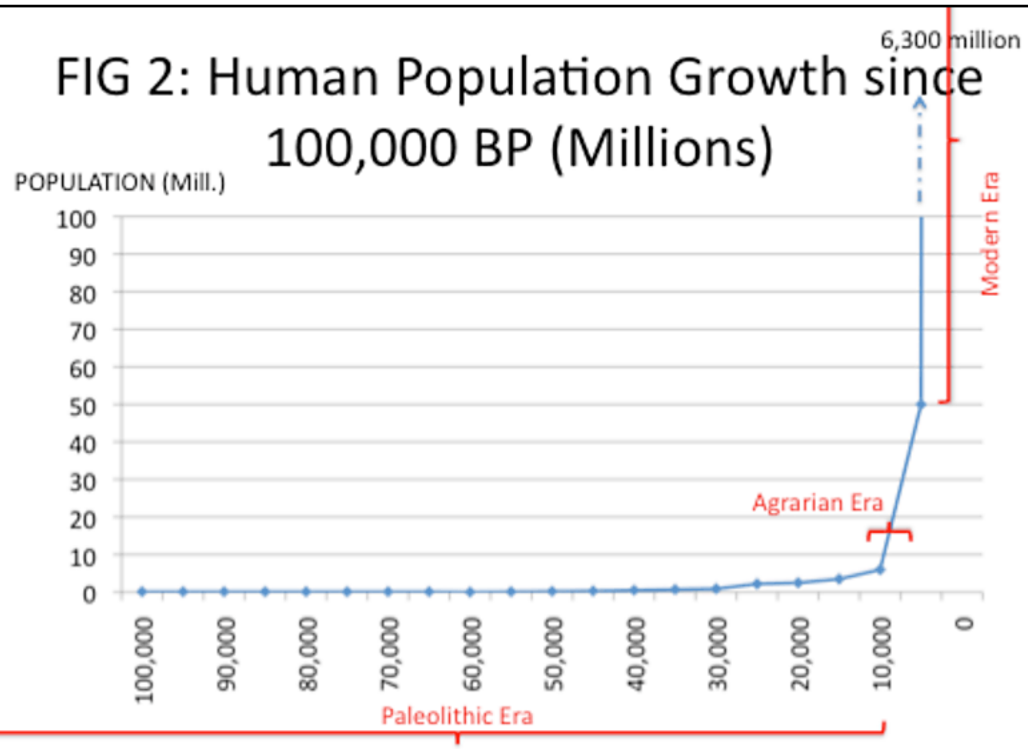
FIG 1: Population Growth in the biological regime

(the numbers are purely illustrative)



Ability to extract resources does not change significantly
Population reaches that limit then fluctuates around it for the rest of the species' history
The "S-curve" typical of animal populations

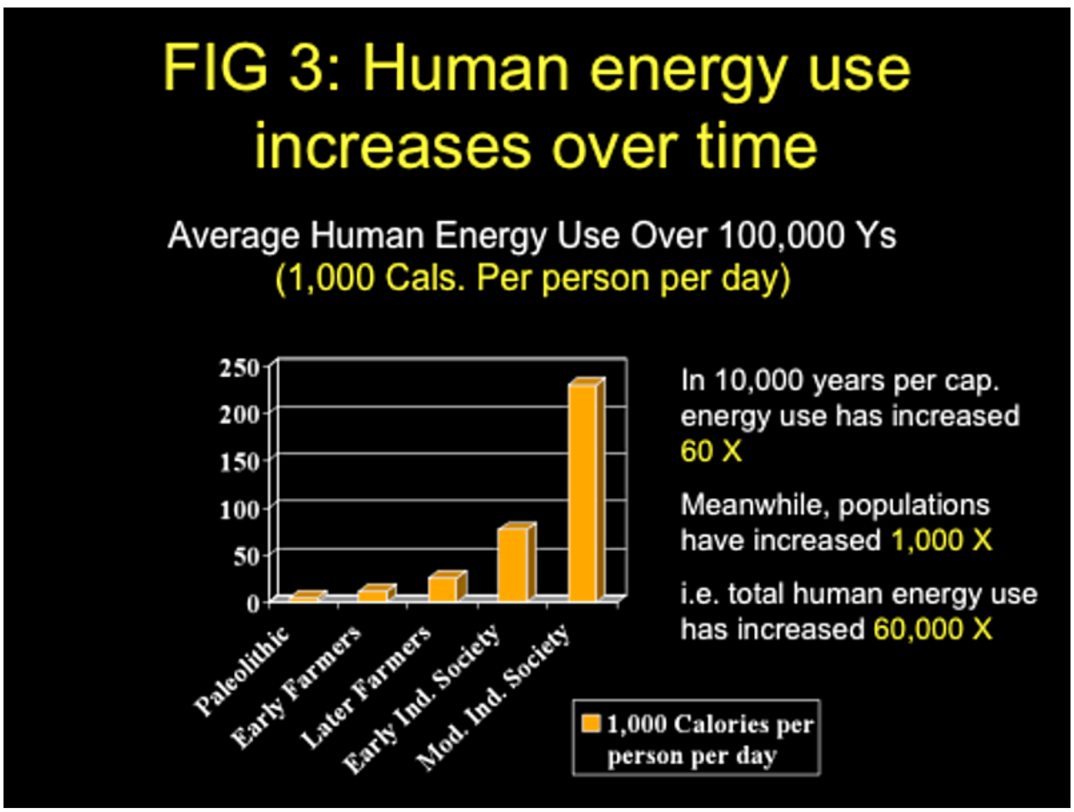
FIG 2: Human Population Growth since 100,000 BP (Millions)



FOR SOURCES: Christian, *Maps of* Time, p. 143, + interpolation

Except, that is, in the case of our own species, *Homo sapiens*. Remarkably, the simple form of the S-curve that I have just described does not characterize the history of our own species. This stunning fact is fundamental to understanding the large patterns of human history.

For most species, the upper bar of the S-curve prevents sustained growth. Our earliest ancestors were also subject to the brutal Malthusian logic of the S-curve.[10] Occasionally, though, they found innovations that allowed them to extract more energy and resources from their environment. These innovations forced the heavy upper arm of the S-curve upwards in small steps, each of which allowed a small increase in populations.[11] At first the steps were tiny and the intervals between them were large, so it is hard to see what is different about the human form of the S-curve. The difference was merely that in human history the upper bar of the S-curve was slowly rising.



Though small, that difference was transformative. It explains our dynamism and creativity as a species. It explains why human cultures display such variety in technologies, organization, clothing, housing, artistic styles, and modes of thought. Yet it also explains why, when seen at large scales, human communities seem to have evolved on parallel trajectories, for in all societies rising populations and increasing control of resources created similar opportunities and challenges that yielded similar outcomes. The distinctive human form of the S-curve explains why we are the only biological species on earth with a history and it explains why that history is patterned.[12]

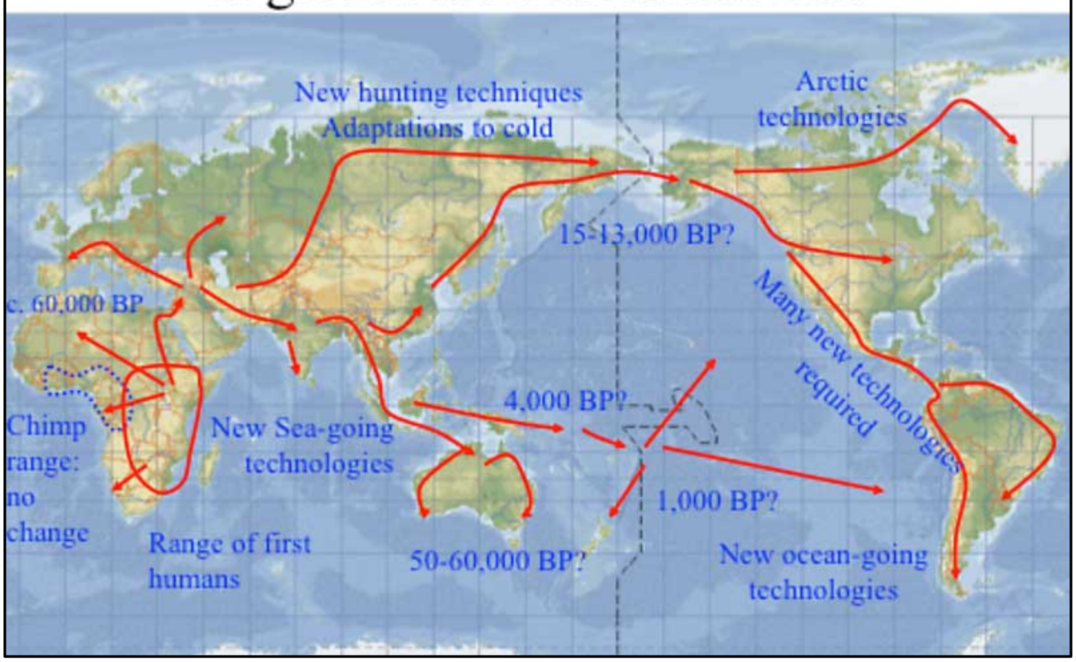
Three versions of the S-Curve

To understand in more detail how the S-curve shaped human history, we must look at how it has worked in different periods. We can distinguish three main patterns.

The first, or "**Paleolithic**," regime characterizes the era before agriculture appeared, about 10,000 years ago. At first sight, graphs of human population growth or energy use may suggest that little changed during the Paleolithic era. That impression is misleading. Our ancestors broke the logic of the S-curve from the moment they first appeared.[13]

Their ecological creativity is easiest to appreciate in the trans-ecological migrations that led small populations to settle new environments within Africa, then in Eurasia, in Australia (perhaps from 50,000 years ago), in ice-age Ukraine, Russia and Siberia, and, certainly by 13,000 years ago, in the Americas. We know of no other large species capable of migrating into such a diversity of environments.

FIG 4: Sustained Technological innovation began in the Paleolithic Era

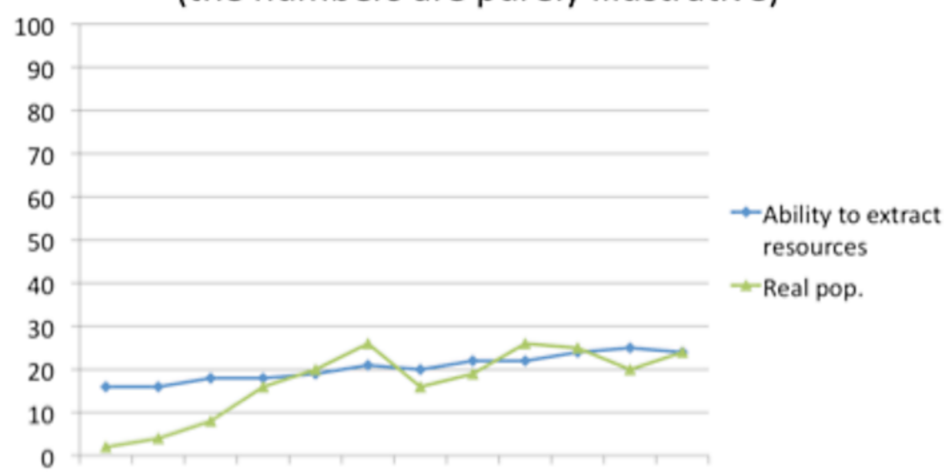


Trans-ecological migrations on this scale required a sustained ability to adapt that is unique to our species. Earlier hominine species, as well as earlier species of elephants, apes and tigers, had migrated between Africa and Asia because, across this vast range, they found familiar environments. But migrating to Australia was a different matter. That required advanced sea-going skills, and the ability to adapt fast to an unfamiliar suite of animals and plants. Our species was the first large land species to make the crossing. Entering ice-age Ukraine, Russia and Siberia was an equally tough challenge. You had to be able to control of fire, to sew well-fitting clothes and hunt mammoth and, in regions of peri-glacial steppe, to construct buildings such as the mammoth-bone houses that Olga Soffer excavated at sites such as Mezhirich.[14] The Americas were settled by populations that had mastered the extreme environments of N.E. Siberia before adapting rapidly to America's astonishing variety of landscapes, climates and species as they traveled from the Arctic to the tropics and then south to Tierra del Fuego in just two or three millennia. Each of these migrations was made possible by "innovations", by new ways of extracting resources from the environment, or new ways of "adapting."

FIG 5: Mezhirich: A Modern Reconstruction

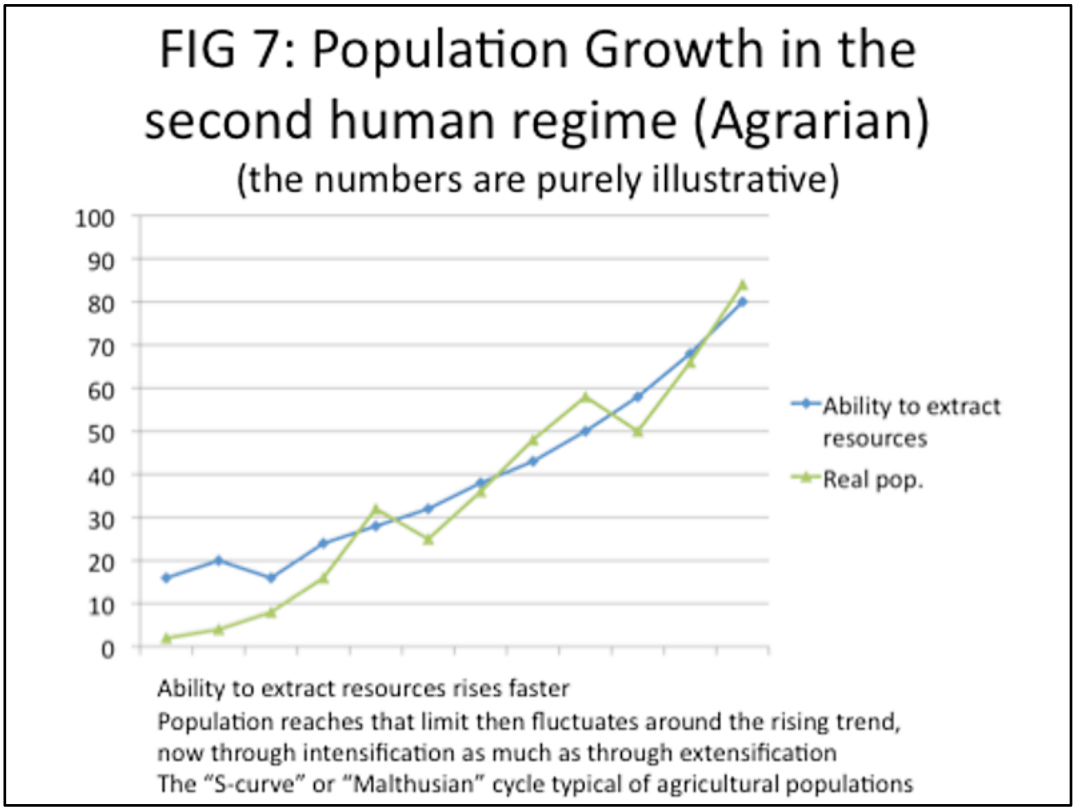
The second, or "**Agrarian**," regime typifies human communities during the last 10,000 years. Most noticeable is a more forceful raising of the upper bar of the S-curve. While this may seem just a matter of pacing, the consequences were transformative. Agriculture, and the technologies associated with it, enabled human communities to settle the world more intensively as well as more extensively, because even the simplest forms of agriculture could support perhaps 50 times as many people as most forms of foraging. Agriculture raised productivity by rearranging landscapes, plants and animals so as to increase the production of those species most useful for humans. From an ecological point of view, the result of processes such as deforestation was often to reduce productivity; for humans what mattered was that agriculture made it possible to siphon off an increasing share of the energy flows generated in the Sun's core and captured through photosynthesis.

FIG 6: Population Growth in the first human regime (Paleolithic)
(the numbers are purely illustrative)



Ability to extract resources rises extremely slowly
Population reaches that limit then fluctuates around it as it rises mainly through widening of the species' range
The "S-curve" typical of foraging populations

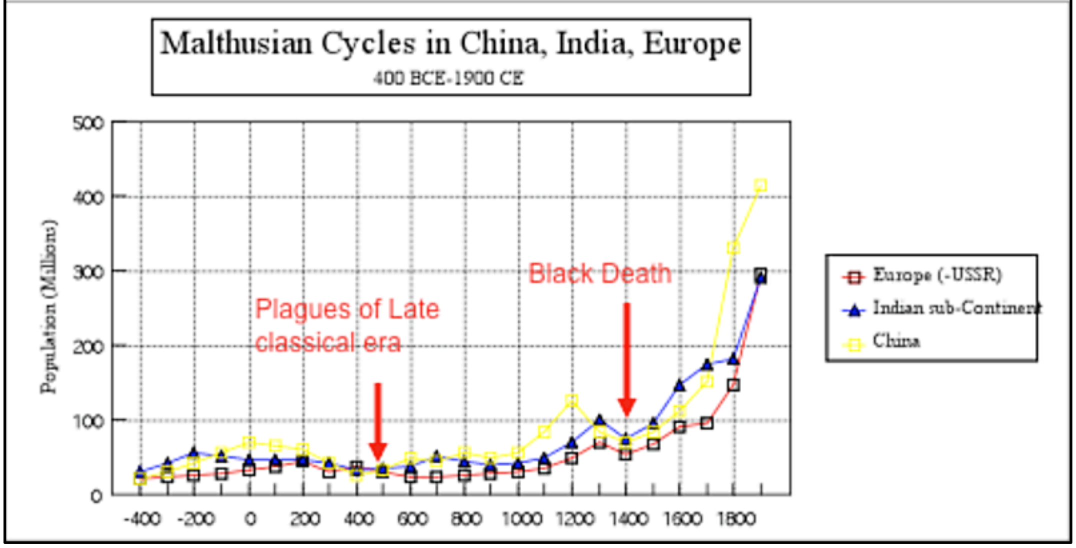
Agriculture could support larger, denser, more variegated and more interconnected human communities.[15] There appeared communities of thousands, even millions of people, engaged in complex relations of exchange, exploitation and conflict. A division of labor emerged as humans used their ecological creativity to find new niches *within* human society, as potters, priests and peddlers.[16] Eventually, there appeared stored surpluses that could support wealthy elites and fund the armies, bureaucracies, trading systems and monumental architecture that sustained and protected their wealth and power.

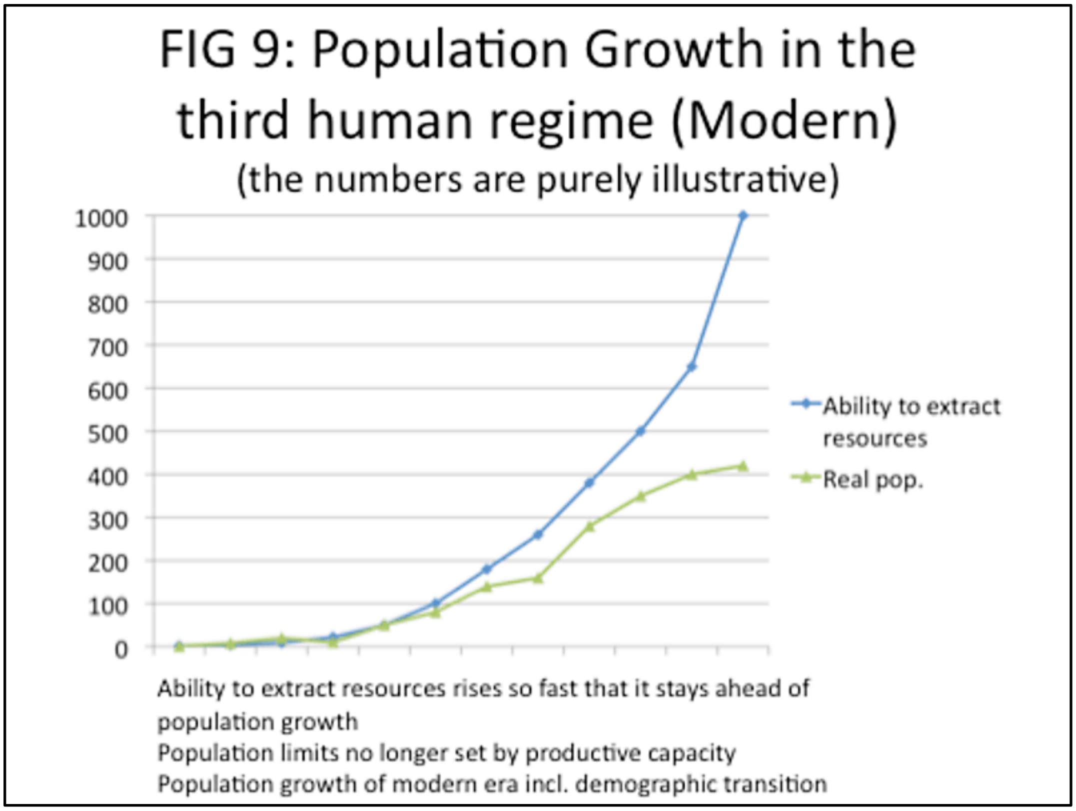


However, even this regime could not escape the iron upper bar of the S-curve, which periodically hammered population growth. There were inherent limits to energy flows because agriculture tapped only recently generated energy. Rates of innovation were also limited by the shortcomings of agrarian era technologies of communications and information storage, and by the generally anti-commercial attitudes and methods of tribute-taking elites. Slow rates of innovation discouraged investment in innovation because the returns were uncertain and remote, which explains why agrarian era elites generally regarded conquest as a more reliable strategy of growth. At the same time populations rose much faster than in the Paleolithic era. Peasants, unlike foragers, have many reasons for maximizing fertility. Small children do not have to be carried, they can be weaned early on cooked grains, and their labor can contribute to the success of a peasant farm. These factors generally encouraged high birth rates, which ensured rapid population growth despite the checks of high infant mortality and high death rates in the unsanitary environments of agrarian era cities and towns. The distinctive combination of sluggish innovation ("technological drift" is what E.L. Jones called it) and rapid population growth ensured that consumption would gobble up most surplus production and wealth would be enjoyed only by small elites.[17]

The sustained pressure of population on resources explains the Malthusian cycles that characterized all agrarian societies—long periods of expansion, followed by rapid decline, disease, warfare, and economic, social and cultural collapse. At first local or regional, by 2,000 years ago, these cycles embraced whole continents.

FIG 8: "Malthusian Cycles": Dominant Rhythm of Agrarian Era





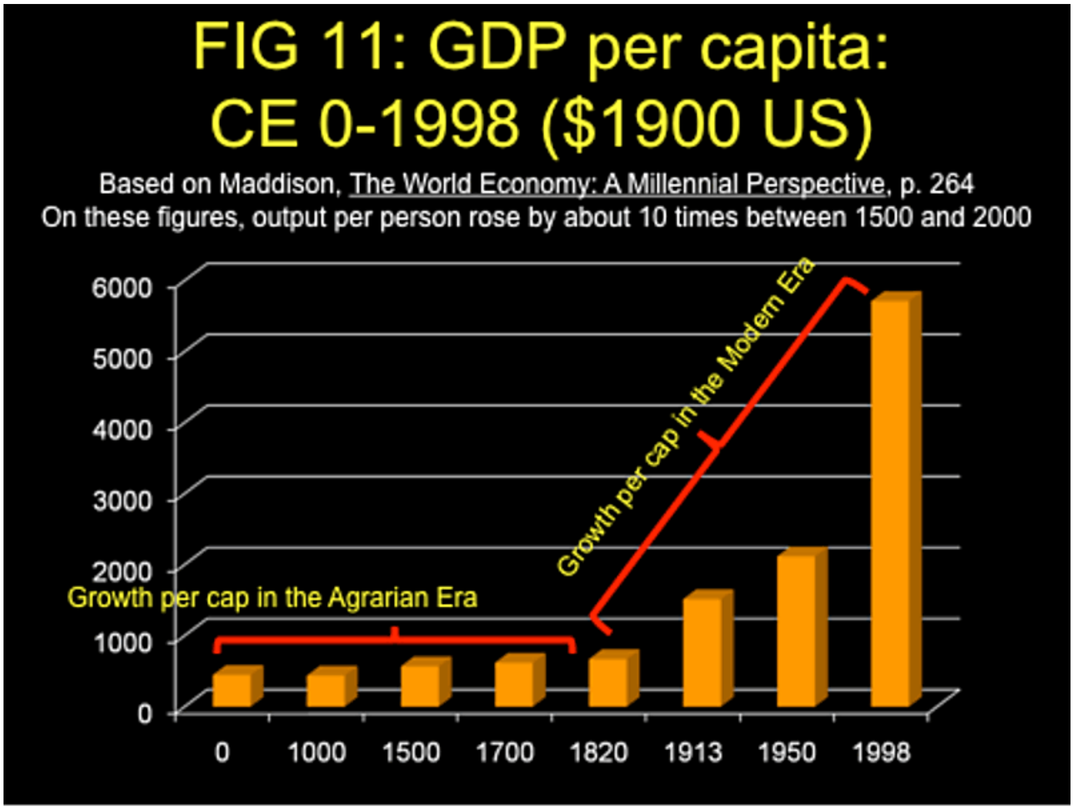
The S-curve, therefore, shaped human history in both the Paleolithic and Agrarian eras. Nevertheless, in both eras cycles of growth and decline can be plotted on a long rising trend of population and resource control, driven by our unique capacity for sustained innovation. Slowly but forcefully human technological ingenuity was stretching the S-curve out of shape. Contemporaries could see the contingencies and the cycles; only in retrospect, can we see the upward trend.

The third, or "**Modern**," regime also began with a simple acceleration in rates of innovation. Yet here, too, there was more than just acceleration. Two important thresholds were crossed. First, efficient ways of exploiting fossil fuels gave humans access to the vast stores of energy accumulated through photosynthesis over 200 to 300 million years, and buried in what Rolf-Peter Sierferle has called the "subterranean forest."[18] Boosted by fossil fuels, human consumption of biospheric resources rose so fast that we have now become a major force for change within the biosphere. Indeed, some scientists argue that we have entered a new geological era, the "Anthropocene."[19]

Second, rising production has lifted the bar of the S-curve so high that (for a while at least) it can no longer do its brutal Malthusian work. For two centuries, human control of resources has increased faster than human populations. This is despite the fact that populations grew faster than ever before because, while fertility rates remained high, death rates (particularly infant mortality) fell with increasing food production, a decline in the regularity and virulence of pandemics and eventual improvements in health care and sanitation. Between 1900 and 2000, populations grew almost four times. Yet grain production rose by about five times, from c. 1.6 billion to c. 6.1 billion tons.[20] Estimates of per capita production provide a more general measure of this transformation. Angus Maddison estimates that global production per capita barely rose between 2,000 years ago and 500 years ago, increasing from about $444 (1990 US$) to just $565.[21] Then things begin to change. By 1820, per capita production had risen to $667 and by 1913 it had taken off, rising to $1,510 by 1913 and to $5,709 by 2000.

FIG 10: GDP per capita: CE 0-1998 ($1990 US)

Year (CE)	Per Cap Production ($1990)
0	444
1000	435
1500	565
1700	615
1820	667
1913	1510
1950	2114
1998	5709

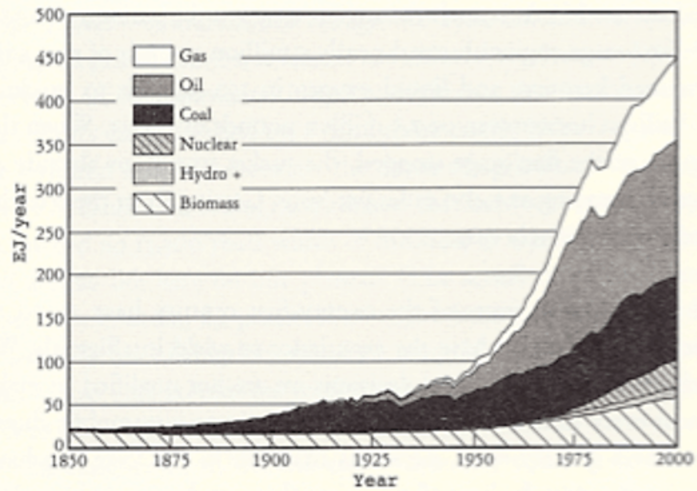


Then birth rates began to fall, closing the temporary gap that had opened between birth rates and death rates. Procreation stopped chasing available resources, as if conceding defeat to human technological ingenuity. By the end of the twentieth century, birth rates were following death rates downwards throughout the world. Increased food production and better health care reduced infant mortality, taking away the need to have extra children as a form of insurance.

Furthermore, the energy bonanza of the fossil fuels revolution devalued physical labor as machines took over the work of humans, while increasing the relative value of *skilled* labor. For households, this meant that children contributed less while young, and their eventual contributions depended more on their skills than on their pure labor power. The best strategy, therefore, was not to maximize fertility, but to have fewer children and educate them better, a change that has transformed gender relations. At a general level, these changes explain both the timing and the geography of the demographic transition.

FIG 12: The Energy Revolution

From Alfred Crosby, *Children of the Sun*, p. 162



Graph of World Energy, 1850–2000

Human energy consumption as measured in exajoules. A joule is the power required to produce one watt for one second; an exajoule is a million million million joules.

This unique conjuncture of increasing resources and falling birth rates has opened a chasm between production and population growth. Modernity arises within that gap as, for the first time in human history, surpluses pulled away from the Malthusian limits set by the upper bar of the S-curve. The expanding gap between resources and populations explains both the best and the worst of modernity: the rising affluence of many modern populations, rising life expectancies, the proliferation of new technologies of communication and information, and also the increasing power of modern states, the destructive power of human weaponry, and the increasing burden our species is imposing on the biosphere.

In summary, in the Paleolithic era, sustained innovation was expressed in a slow increase in the range of our species. In the agrarian era, more rapid innovation generated surpluses that supported more complex societies, though rapid population growth periodically checked the growth of surpluses ensuring they would enrich only small elites. Finally, in the modern era, even more rapid innovation generated surpluses so large that they were not gobbled up by population growth, and human beings seemed (for a time at least) to have escaped from the Malthusian constraints of the S-curve.

Explaining the Trends

In history as in science, patterns, once identified, invite explanation. Can we explain the distinctive forms the S-curve has taken in the history of our species? And by doing so can we clarify the complex relationship between contingency and pattern in human history? I believe there is indeed a simple but powerful explanation for some of the larger trends. I will describe that explanation briefly as I have described it at length elsewhere.[22]

The feature that distinguishes human history most powerfully from the histories of all other species is our capacity for sustained innovation. Innovation, like "adaptation" in the biological world, means finding new ways of extracting resources and energy from an environment. So I will treat "adaptation" and "innovation" as synonyms, particularly when they generate behaviors that increase control of biospheric resources. In the biological realm, each species is defined, roughly speaking, by its unique innovation. The finches Darwin observed on the Galapagos Islands each had a beak adapted to exploit the trees and seeds unique to its home island. This means that you normally get one major innovation per species. Humans are different because the innovations/adaptations keep coming. Why?

Natural selection is not the only adaptive mechanism in the biological realm. A second mechanism is learning. As they mature, animals with brains can learn better ways of coping with their environment (improved strategies for hunting or hiding, for example). In fact, that is how brains (which are expensive organs) pay their way. But this form of adaptation has a limited impact because it works at the level of the individual not the species. Individuals can share little of what they have learned, so each individual has to start more or less from scratch. New information cannot accumulate at the level of the population or the species, so we see no long-term change in the behavior of the species. We find no "history." Of course in many species individuals can and do exchange some information. But there is a critical threshold here, the point at which exchanges of information become so efficient, so pervasive and so significant that more information is exchanged than is lost. Only then are we likely to find the sort of archaeological evidence that we find only for our own species, of significant innovation over time, of "history."

The prerequisite for this sort of change is a highly efficient mechanism for sharing and storing the information learnt by individuals in forms that are accessible to the group as a whole. What is needed is a sort of collective brain that can collect and process the information contributed by its human neurons just as the internet pools information from individual computers. Assuming that the collective brain, like all containers, will leak, there must be redundancy: communication must be so efficient that more information is stored than is lost through the misunderstandings, miscommunications and malfunctions present in all systems of communication.

In symbolic language, humans have evolved just such a system. Animal languages are limited, for the most part, to individual utterances, similar in their communicative power to shouts of alarm or gestures of pointing. They cannot describe what is not present so they cannot describe the past or future or the monster in the forest. They cannot exchange the precise, though imaginary pictures I can send with the two words: "pink elephant;" or the rich swarm of meaning that buzzes around a word like "God." Symbolic language can do all these things because it uses words symbolically and arranges them in rich but precise patterns through syntax. Human symbolic language has crossed a threshold of communicative efficiency that allows more information to be stored in the collective brain than is lost. Once that threshold has been crossed learned information can begin to accumulate, generation by generation, within the collective brains of human "cultures."

We can call this powerful new adaptive mechanism "collective learning." It is unique to our species. It has increased the adaptive power of our species by orders of magnitude because the collective brains of human culture have a power, efficiency and longevity much greater than individual brains, and, unlike individual brains, their power can, in principle, expand without limit.

The idea of collective learning helps explain several of the large patterns of human history. As new information accumulates within human communities, collective learning generates the constant trickle of innovations that drives human history. To appreciate the implications of this simple idea it may help to imagine a huge, multi-dimensional landscape of ecological possibilities that exist like unused ecological niches until eventually some are discovered in reality. That landscape has its own distinctive geography. It contains objects both large and small, and they are arranged in predictable sequences so that, for example, stone tools can be found closer to the origins of our species than steam engines. This metaphor is familiar to biologists, who know that the rules of chemistry and physics and the distinctive features of our planet limit the number of possible adaptations. Some evolutionary pathways are excluded entirely; some are remote and may never be found; while others are more common, so that the landscape itself steers natural selection towards some paths rather than others, and it does so in logical sequences because some pathways can only be reached through others. Adaptations, like innovations in human history, were out there waiting to be found.

The metaphor of a landscape of adaptive possibilities helps explain why some evolutionary pathways (such as the evolution of eyes) have been entered quite independently by many different lineages, in a process biologists call "convergent evolution."[23] It may also help us understand why some pathways, including collective learning, were extremely hard to find (on our planet, this particular journey took almost four billion years); while other pathways, once found, could open up entirely new evolutionary landscapes. Human beings, like life in general, have been exploring this imaginary landscape of ecological possibilities. What makes us different is that we explored it with the aid of collective learning. That explains why our ancestors explored it so fast and so thoroughly, and why they entered pathways no other species had found.

Retroactively, the idea of collective learning can help us predict some general features of the human journey through this imaginary landscape, just as we can predict how much of a chunk of Uranium is likely to have decayed in a given period. First, we can predict that the pace of innovation was likely to accelerate in the course of human history. This is because collective learning initiates a powerful feedback cycle. It is autocatalytic. Innovations increase available resources, allowing population growth, which increases the number of individuals adding to the information within the collective brains of regional communities, thereby encouraging more innovations, and so on. No wonder when we look at very long trends such as population growth, we see acceleration.

The same ideas help explain why human history was also likely to be a story of increasing social complexity. Here, though, the pattern is not so smooth. In the Paleolithic era, despite increases in the range and population of our species, the size of human communities changed little. Indeed modern studies of foraging communities suggest that our ancestors may have systematically limited fertility, though never, apparently, with enough success to remove all pressure to innovate and migrate. Not until the end of the Paleolithic era do we find evidence of a gentle increase in the size of some communities in areas of abundance such as southern France, where Upper Paleolithic communities followed large herds of reindeer. So, for most of the Paleolithic era, humans lived in small and relatively simple family groups that periodically met with neighboring families to form extended networks of a few hundred individuals. This pattern of innovation leading to migration could continue only until humans had occupied all habitable regions of the earth. That frontier was reached, coincidentally, at the end of the last ice age, about 10,000 years ago. Agriculture broke through these limits, raising productivity sharply and giving rise to larger and denser communities, within which new problems of coordination and conflict-management emerged, eventually creating the large, complex communities of the agrarian era.

These arguments suggest that the appearance of cities, of states, of monumental architecture, of writing, of trade … all these changes, though long delayed during the Paleolithic era, were implicit in our capacity for collective learning. But agricultural technologies, too, had limitations and sustained innovations made it likely that these, too, would eventually be transcended. In other words, barring extreme contingencies, it was likely from the time our species first appeared that human societies would cross the major thresholds associated with agriculture and the industrial revolution.[24] We can imagine these transitions happening in different regions, or occurring thousands of years earlier or later than they did in fact. But eventually, they would have happened. In short, the idea of collective learning, for all its simplicity, predicts the long trend to increasing social complexity that we find in human history.

Explaining the Turning Points

However, when we try to explain the timing and geography of major changes, such as the different demographic regimes we have described, contingency and agency loom larger.

The great turning points of human history were caused not by routine innovations, such as the slow genetic changes that allowed domesticated maize to travel north from its Mesoamerican homelands, but by mega-innovations. These were reached through paths that, like remote mountain passes, were difficult to find, but when crossed revealed entirely new landscapes. Mega-innovations were so powerful they could transform the geographical balance of power and wealth between different societies, and impose change on societies that resisted them. That someone would eventually stumble on these pathways was likely and even, in a general sense, predictable. But who would stumble across them and when was a more contingent matter, a bit like striking gold.

The first mega-innovation was symbolic language, the ultimate source of the cascade of changes we call human history. Though the pathway leading to collective learning was remote, as brains grew in size within some evolutionary lineages the likelihood of finding it increased. However, as with all speciation events, the timing was contingent, depending as it did on random genetic changes. It was as unpredictable as the breakdown of a particular atom of Uranium. It might have taken millions of years more or less than it did in fact. We do not know exactly what changes opened the door to symbolic language and collective learning, but the sharp transition between our own species and those closest to it suggests that the changes happened fast and there were few of them. Perhaps a minor switch was thrown in parts of the brain associated with communication or gesture or sound production.[25]

Agriculture, the second mega-innovation in human history, opened up entirely new ways of controlling energy flows captured through photosynthesis and transmitted through domesticated crops and animals. The abrupt chronology of the agricultural revolution arises from an unpredictable conjuncture between a human process (by 10,000 years ago foragers had colonized the planet) and a meteorological process, the end of the last ice age. Warmer, wetter climates raised the natural productivity and abundance of species such as grains and the herbivores that fed on them, and humans began to exploit them more intensively. The geography of the agricultural revolution was determined largely by the presence in particular regions, such as the fertile crescent, of highly productive plants and animals that could be readily domesticated.[26] Of course, this is not to say that innovation only occurred in these regions, for we can be sure that foragers continued to innovate as they had throughout human history. It is just that the first farmers had stumbled onto a mega-innovation. The high productivity of agriculture encouraged population growth and accelerated technological change so that agriculture spread around the world, adapting to many different environments, and generating core regions of dense population, rapid innovation, and increasing demographic, political, military and commercial power. These regions of dense agrarian populations slowly transformed the communities in their hinterlands. The diffusion of agriculture from a number of independent origin points provides one of the dominant patterns of the last 10,000 years.[27]

However farmers, like Paleolithic foragers, would eventually encounter ecological frontiers, set not only by lack of space, but also by the limited energy available from technologies based on energy flows from recent photosynthesis. In this way, exploration of the possibilities of agricultural technologies over 10,000 years prepared the way for the next turning point, the industrial revolution.

With the industrial revolution, we enter territory so familiar that it is peculiarly difficult to see the large patterns. Yet here, too, adequate explanations must do justice both to the contingencies and to the large patterns. This section will attempt to link the arguments of this paper with the fine recent research on the Industrial Revolution by world historians.[28]

It may help to think of the industrial revolution as the result of two closely linked mega-innovations: the unification of the world in the sixteenth century and the fossil fuels revolution. In a general sense, the long trends of the agrarian era help explain the timing of these changes. The slow expansion in the scale and efficiency of exchange networks prepared the way for the first, while improvements in technology, particularly in metallurgy and science, combined with increasing pressure on existing energy sources, prepared the way for the second.

There is a clear link between these mega-innovations. By linking once distinct world zones into a single global system the first pulse of globalization created webs of exchange that were larger and more diverse than any that had ever existed before. The many collective brains of the agrarian era began to join to form the global collective mind of today's world. Within global networks of exchange, people, goods, wealth, crops, technologies and ideas circulated more rapidly and more widely than ever before, increasing the likelihood of stumbling on to new mega-innovations. Further, as a result of what Alfred Crosby called the "Columbian Exchange," the work of the agricultural revolution was completed in a sudden rush as agriculture spread to regions such as Australasia where it had been absent before.[29] The weaving of a single global network of exchange had one more important consequence: it ensured that the next mega-innovation would spread so rapidly that it could only happen once. Who would stumble across the next mega-innovation was, therefore, a matter of exceptional historical significance. Just as the agricultural revolution boosted the wealth and power of regions of early agriculture, so the fossil fuels revolution had an even greater impact, in this case on N.W. Europe, a region previously on the periphery of the world's major exchange networks.

Why Europe? The arguments presented above suggest that it is not enough to show that European societies were innovatory. All human societies innovate, and recent research suggests that early modern Europe was not exceptional in this regard. But European societies were the first to stumble on the two mega-innovations that ushered in the modern era. This surely counts as a lucky strike, for no one could have predicted in advance the vast synergies these mega-innovations would release.

There are many familiar explanations for Europe's distinctive role in the creation of the first global networks of exchange. Bridging the Atlantic was perhaps easier than bridging the Pacific. And once the Atlantic had been bridged, Europe ceased to be a mere periphery, but found itself on the rim of new networks whose importance would increase rapidly over the next few centuries. The Spanish windfall showed what could be gained through such networks, and encouraged Spain's European neighbors to actively seek participation in them. But why did European governments and merchants make the initial efforts needed to build these global networks? Initially, their aim was to link up with the huge trade systems of S.E. Asia. Europe's semi-peripheral status in Eurasian trading networks and the blocking of European access to Asian trade networks, encouraged European governments and merchants to force their way onto the vast trade networks of South and East Asia, while the military innovations generated by sustained competition between European states gave them the power to do so.

Within Europe the leading role in entering these networks was played at first by Spain and Portugal, then Holland. But the whole of W. Europe benefited to some extent by new flows of wealth (particular American silver drawn through Europe to the huge markets of E. and S.E. Asia), so that Europe's distinctive position within the new, global networks of exchange generated new wealth and an increasing flow of new ideas, in the course of the "Scientific Revolution" and the Enlightenment. In short, we can explain why European governments and mercantile elites fought to join global networks of exchange and innovated in distinctive ways, but that is different from explaining the vast economic, military and commercial benefits they gained by taking these particular pathways.

Europe's new position within global networks of exchange helps explain why several societies in N.W. Europe enjoyed rapid growth buoyed by increasing commercial wealth and an intensified circulation of new ideas, technologies and goods. As we have seen, such periods of growth were common in the agrarian era. Jack Goldstone has described them as "efflorescences:" periods of rapid regional growth and innovation, eventually checked by the Malthusian upper arm of the S-curve and by slowing innovation.[30] Pushed by the rising costs of war and pulled by the benefits of participation in global trade networks, European governments actively supported commerce, and the technological and institutional innovations needed to support it through mercantilist policies and the building of protected markets in overseas colonies. But such policies were not unique. In the early modern period, there was significant commercial growth right around the rim of Eurasia, perhaps most rapidly in Qing China.[31] In a sense, as Goldstone has argued, European growth in the 17th and 18th centuries was merely one more routine efflorescence, allowing the region to catch up with, but not to surpass the traditional power centers of E. Asia.

The intellectual exchanges within global networks of exchange may be as critical as the commercial exchanges, for here Europe's centrality in global networks ensured it would become a sort of clearing house for the first world-wide intellectual exchanges. If there was an innovation of importance, it was likely that European innovators would know about it. Perhaps as a result of the sheer volume of information, there developed in Europe, and particularly in Britain, an unusually exploratory attitude to scientific knowledge. Goldstone has pointed out that there was a peculiarly practical edge to innovation in Britain, and that may help explain why British entrepreneurs were responsible for an unusual number of innovations in the 18th and early 19th centuries.

However, given the peculiar power of the fossil fuels revolution, we must also grant a vital role to the contingent fact that Britain was sited on the "carboniferous crescent" from Scotland to the Ruhr. If Britain had lacked coal, it is hard to see how the Industrial Revolution could have taken off there, despite the inventiveness of its engineers and entrepreneurs.[32] In this sense Britain was, as Ken Pomeranz puts it, a "fortunate freak."[33] Fossil fuels gave a colossal advantage to the society first able to exploit them. By 1850 British per capita use of energy was more than ten times that of the rest of the world, while by 1900 Britain supplied 25% of the world's energy though its population was only 3%.[34] Translated into wealth and power, that differential goes a long way to explaining the astonishing cultural, economic and political power of Britain and other early industrializing societies.

In summary, the large patterns of human history suggest that something like the Industrial Revolution was going to happen eventually, while the patterns of history since the Agricultural Revolution offer some general hints as to its timing and suggest it was most likely to occur somewhere in the Afro-Eurasian world zone. But it was a largely (though not entirely) contingent fact that the two great mega-inventions of modernity—creation of the first global networks of exchange and the fossil fuels revolution—both boosted commercial growth and innovation in a particular part of the world, along the N.W. shores of the Afro-Eurasian landmass.

It goes without saying that this brief discussion cannot do justice to the complexity of a transition as complex as the industrial revolution. I hope, however that it demonstrates the importance of to see the large patterns as well as the more contingent twists and turns that lay behind such turning points. In history, as in science, contingency and pattern are not exclusive but complementary mechanisms, as Kant pointed out more than two centuries ago. To focus almost entirely on the contingencies is to miss half the story.

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Notes

1 My thanks to Craig Benjamin and Daniel Headrick for comments on an earlier version of this paper

2 Alvarez (who currently teaches a big history course at UC Berkeley) has written a wonderful account of the research that led to this discovery in Walter Alvarez, *T. Rex and the Crater of Doom*, London: Vintage, 1998

3 R.G. Collingwood, *The Idea of History*, rev. ed., ed. Jan Van der Dussen, Oxford and New York: OUP, 1994, 214

4 Joyce Appleby, Lynn Hunt, and Margaret Jacob, write: "the human sciences, such as history, have a distinct set of problems. Any analogy to natural science falters because the historian or sociologist, even the economist, cannot effectively isolate the objects of inquiry. … Humanists study action which is responsive to intentions, whereas naturalists investigate the bounded world of behavior." *Telling the Truth about History*, New York: Norton, 1994, 252

[5] Laplace, Pierre Simon, *A Philosophical Essay on Probabilities*, translated from the 6th French edition by Frederick Wilson Truscott and Frederick Lincoln Emory, Dover Publications (New York, 1951) 4

[6] Immanuel Kant, "Idea for a Universal History from a Cosmopolitan Point of View," in *Kant on History*, ed. Lewis White Beck, New York: Macmillan, 1963, 11-26, from 11-12

[7] Colin Renfrew, *Prehistory: The Making of the Human Mind*, London: Modern Library, 2008, 74-5

[8] Renfrew, Prehistory, 71; Renfrew points out that Robert Adams, who did pioneering work on the parallels between Mesopotamia and pre-Columbian America, argued that both societies were clearly "variants of a single processual pattern."

[9] Both quotations from *Thomas Robert Malthus: An Essay on the Principle of Population*, ed., Philip Appleman, New York and London: Norton, 1976, xiv

[10] Current estimates of when our species appeared range from c. 60,000 years ago to about 250,000 years ago. For arguments defending these different dates for the beginning of human history, see Richard Klein with Blake Edgar, *The Dawn of Human Culture*, New York: JohnWiley & Sons, 2002, and Sally McBrearty and Alison Brooks, "The Revolution That Wasn't: A New Interpretation of the Origin of Modern Human Behavior," *Journal of Human* Evolution, 39 (2000): 453-563; for a summary of these debates, see Paul Pettit, "The Rise of Modern Humans," in Chris Scarre, ed., *The Human Past: World Prehistory and the Development of Human Societies*, London: Thames & Hudson, 2005, Ch. 4

[11] We have no direct evidence on populations in the Paleolithic era, but we do have plausible estimates which are summarized in the table in David Christian, *Maps of Time: An Introduction to Big History*, Berkeley, CA: University of California Press, 2004, 143

[12] Is it necessary to add that this is not an argument about progress? It is an argument about empirically observable trends in human history, of which the most important is a trend towards greater collective control of biospheric resources that allows human populations to increase. Whether these trends are "good" or "bad" is an entirely different, and extremely complex question. What I do argue is that they provide some powerful clues about the nature and meaning of human history.

[13] Some of the early evidence is described in McBrearty and Brooks, "The Revolution that Wasn't"

[14] Olga Soffer, *The Upper Palaeolithic of the Central Russian Plains*, Orlando: Academic Press, 1985

[15] A century ago, Émile Durkheim had already argued that the main drivers of increasing social complexity or "social density" were increasing population density and improved means of communication. See Randall Collins, *Three Sociological Traditions*, N.Y.: Oxford University Press, 1985, 125

[16] Durkheim pointed out that where humans are forced to live in dense communities, specialization is the only alternative to mutual elimination. Steven Lukes, *Emile Durkheim: His Life and Work, a Historical and Critical Study*, Stanford: Stanford University Press, 1985, p. 171. Similar rules also operate in the biological world, where species competing for similar niches often evolve specializations that complement each other; see Eugene P. Odum, *Ecology and Our Endangered Life-Support Systems*, 2nd ed., Sunderland, MA: Sinauer, 1997, 167, 170

[17] See E.L. Jones, *The European Miracle: Environments, Economies, and Geopolitics in the History of Europe and Asia,* 2nd ed., Cambridge: Cambridge University Press, 1987, Ch. 3

[18] Rolf-Peter Sieferle, *The Subterranean Forest: Energy Systems and the Industrial Revolution*, Cambridge, Eng.: The White Horse Press, 2001

[19] The term was first proposed by Paul Crutzen in 2000. See Crutzen, "The Geology of Mankind," *Nature*, Vol. 415, (3 January 2002), p. 23; and also Jan Zalasiewicz et. al., "Are we now living in the Anthropocene?", *Geological Society of America*, Vol. 18, No. 2 (Feb 2009),4-8

[20] Data from David Christian, *Maps of Time*, 442-3

[21] Angus Maddison, *The World Economy: A Millennial Perspective*, Paris: OECD, 2001, 264

[22] For example in David Christian, *Maps of Time*, particularly Ch. 6

[23] The idea that natural selection, like collective learning, explores a structured imaginary landscape of possibilities is discussed in Simon Conway Morris, *Life's Solution: Inevitable Humans in a Lonely Universe*, Cambridge: Cambridge University Press, 2004

[24] Contingent catastrophes were a real possibility. There are powerful genetic hints that about 70,000 years ago, for reasons that remain obscure, but may include sharp climatic changes or major volcanic eruptions, the number of humans fell sharply to just a few thousands. See Chris Scarre, ed., *The Human Past: World Prehistory and the Development of Human Societies*, London: Thames & Hudson, 2005, 139-40

[25] Richard Klein suggests, for example, that there was "a genetic change that promoted the fully modern brain in Africa around 50,000 years ago." Richard Klein with Blake Edgar, *The Dawn of Human Culture* (New York: Wiley, 2002), 8

[26] See Peter Bellwood, *First Farmers: The Origins of Agricultural Societies*, Oxford: Blackwell, 2005, and Jared Diamond, *Guns, Germs and Steel: The Fates of Human Societies*, London: Vintage, 1998, particularly Ch. 7

[27] John R. McNeill writes, for example, that: "This slow frontier process [the expansion of the agrarian frontier] is the main theme of world environmental history between the emergence of agriculture and modern times." "Bridges: World Environmental History: The First 100,000 Years," *Historically Speaking* 8:6 (July/August 2007), 6-8, cited from 7

[28] Good summaries of recent research can be found in Robert Marks, *The Origins of the Modern World: A Global and Ecological Narrative from the Fifteenth to the Twenty-first Century*, 2nd ed., London & NY: Rowman & Littlefield, 2007, and Jack Goldstone, *Why Europe? The Rise of the West in World History, 1500-1850*, Boston: McGraw-Hill, 2008

[29] Alfred W. Crosby, *Ecological Imperial Imperialism: The Biological Expansion of Europe, 900-1900*, Cambridge: Cambridge University Press, 1986; John F. Richards gives a superb account of the final global sprint of the agricultural revolution in *The Unending Frontier: An Environmental History of the Early Modern World,* Berkeley: University of California Press, 2003

[30] Jack Goldstone, "Efflorescences and Economic Growth in World History: Rethinking the 'Rise of the West' and the Industrial Revolution." *Journal of World History*, Vol. 13 (2002), No. 2, 323-89

[31] See Victor Lieberman, ed., *Beyond Binary Histories: Re-imagining Eurasia to c. 1830*, Ann Arbor: University of Michigan Press, 1999, and Jack Goldstone, *Why Europe?*

[32] John McNeill and William McNeill write that this region was as important in the Industrial Region as the "fertile crescent" was in the agricultural revolution, and for the same reason: it happened to have the crucial resources needed for the breakthrough to new and more productive technologies. J.R. McNeill and William H. McNeill, *The Human Web: A Bird's-Eye View of World History*, N.Y.: Norton, 2003, 231

[33] See Tom Laichas, "Ken Pomeranz: An Interview", in *World History Connected,* Vol. 5, Issue 1 (October 2007)

[34] Goldstone, "Efflorescences", 364