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LePoire, David John

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Exploring Phenomenological Models for Societal and Technological Transitions of the Neolithic Revolution and Early Civilization Formation

David John LePoire

Argonne National Laboratory

Several qualitative models have been proposed to explain significant historical shifts in both societal and technological domains. Despite advancements in modeling, certain transitions remain enigmatic, such as the early shift from hunter-gatherer to agriculture-dependent societies, marked by a substantial increase in effort. Another perplexity involves the coordination of agricultural activities into cities and civilizations, despite the larger overhead effort and loss of independence. The exploration of simplified models featuring aggregate, dynamic, and nonlinear processes holds the potential to uncover distinctive facets of each transition. The transitions under consideration span from hunter-gatherer societies to agricultural societies and then to early civilizations. Other analogies are suggested for further exploration for transitions to market systems, capitalism, industrialization, and sustainable societies, incorporating factors like land pressures, economies of scale, suppressed growth, and chain reactions.

Diverse modeling approaches can be employed for these transitions. Initially, fundamental characteristics, such as the width and midpoint of transitions, are deduced by analyzing historical events influencing the transition. However, this approach offers limited insights into the dynamics or parameters of the transition. For a more comprehensive understanding, two historical transitions are examined using a simple phenomenological model. These simplified models do not aim to quantitatively address the intricate details of actual historical mechanisms; instead, they leverage analogies to natural systems to gain insights.

Corresponding author's e-mail: dlepoire@anl.gov

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Introduction

Questions in Major Historical Transitions. In Big History studies, numerous transitions mark the trajectory of increasing complexity in both natural ecosystems and socio-historical development (Christian, Stokes-Brown, and Benjamin 2014; Volk 2017; LePoire 2015). This paper concentrates on historical transitions that are amenable to analysis and historical inquiry. While the consequences of these transitions have been extensively documented, fundamental questions persist regarding the underlying reasons for these transformative shifts. For instance, what motivated early farmers to abandon the seemingly simpler lifestyle of hunter-gatherers? (Bowles and Choi 2019) Why did ostensibly parasitic cities, reliant on the agricultural output of their surroundings, emerge on a large scale? Why did the scientific and industrial revolutions predominantly unfold in Western Europe, even when many of the foundational innovations were imported from other regions? (Goldstone 2009). A contemporary question also looms: Can a civilization heavily reliant on unsustainable fossil fuel consumption chart a course toward sustainable productivity?

In the context of natural ecosystem transitions, external environmental changes often act as catalysts for evolution. These alterations encompass geological shifts, such as drifting continents shaping and erasing seas, and the sun's gradual warming from its inception roughly 5 billion years ago to the present, accompanied by changes in its elemental composition. However, some changes result from evolution itself, exemplified by phenomena like the Devonian-era arms race of jaws and the development of oxygen generation—initially toxic to early life—until a regulatory mechanism evolved to control the oxidation process (Fewster 2016).

In human evolution, changes appear to mirror the latter category—internally generated (Ponting 2007). Each period resolves challenges from the previous one, thriving until new limits are encountered, giving rise to fresh predicaments. Explorations for alternative solutions, including new technologies and organizational structures, commence. Some challenges manifest as constraints on human population within a particular lifestyle and the management of energy and its corresponding environmental impacts. When established solutions prove inadequate, endeavors in reform, reorganization, and new insights ensue (Tainter 1996; Gunderson and Holling 2002). For instance, many energy sources pose significant dangers without proper control—early humans mastered the control of natural fires that could have otherwise devastated their surroundings. Agricultural villages facilitated increased food (energy) production but introduced new challenges in human waste disposal and disease. Present-day energy sources generate substantial pollution, such as CO2 emissions and nuclear waste, necessitating ongoing efforts to develop effective controls and sustainable alternatives.

Major Historical Transitions

Prominent historical transformations encompass the shift from hunter-gatherer societies to an agrarian lifestyle during the agricultural revolution, the adoption of external energy sources for extensive manufacturing in the industrial revolution, and the ongoing transition towards a more sustainable lifestyle, detached from fossil fuels (Fewster 2016). However, intermediary periods marked significant connecting changes. For example, following the establishment of farming villages, a pivotal transformation unfolded with the emergence of larger cities specializing in non-agricultural pursuits like governance, religion, and law. The onset of ancient and classical civilizations, around 3000 BCE, featuring renowned societies like Egypt, Mesopotamia, China, and the Indus Valley, persisted until the collapse of the Roman Empire around 476 AD—an epoch highlighted by Rome, the largest city of the ancient world. Similarly, the Chinese Han Dynasty, spanning over 400 years from 206 BCE to 220 AD, showcased an enduring civilization.

In contrast, the industrial revolution did not materialize promptly; rather, it unfolded over a millennium as the economic groundwork for this transformative era took shape. Competing political entities evolved, integrating burgeoning labor forces, technological advancements, and natural energy sources such as wind, water, and wood. The scarcity of workers post the mid-14th century Black Death calamity facilitated a labor market. Substantial investments in trading ships were enabled by financial instruments like loans, stocks, and insurance. As companies grew more efficient, the trade of luxury items expanded to include trading in bulk commodities like wood, fish, and salt. Sustainable growth for these trading enterprises stemmed from reinvesting profits into critical infrastructure like ports and ships.

Potential modeling approaches

The modeling of these transitions can be approached at various levels of abstraction to offer diverse perspectives (Costanza, Wainger, Folke, and Mäler 1993; Turchin 2003). Engineering models, for instance, exhibits attributes of realism, precision, and generality. Models with high realism aim to capture underlying mechanisms at their fundamental levels. Conversely, high-precision models may sacrifice fundamental understanding in favor of empirically derived coefficients. General models, falling in between, are based on intermediate conceptual frameworks that emphasize qualitative mechanisms, although they might be limited in numerical predictions and detailed mechanisms.

A straightforward logistic model delineates the transition between two populations, where the transition rate is proportionate to a constant multiplied by both populations, resulting in an "S-curve" growth. Empirical logistic trend analysis models could find support through the examination of significant events, energy usage patterns, and political successions.

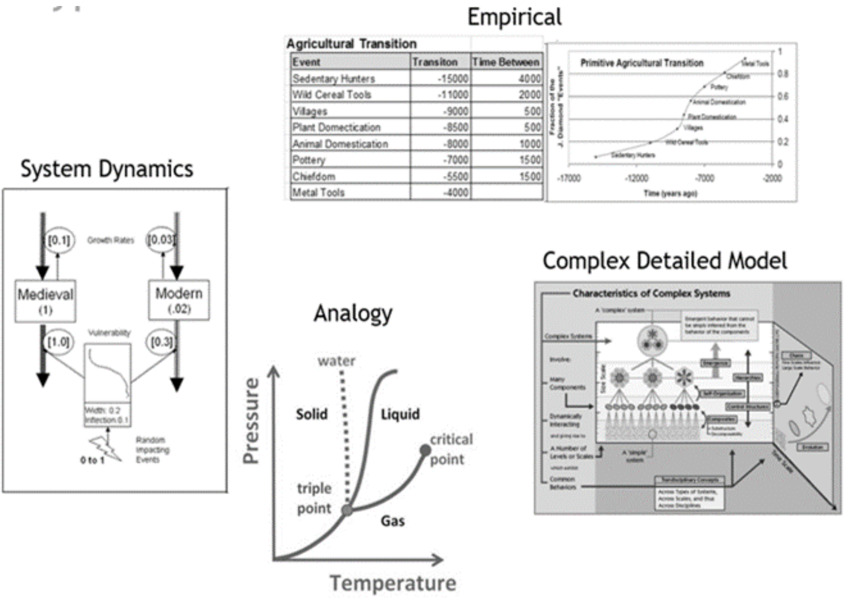
Going beyond the simplicity of the logistic model, this study endeavors to comprehend, at a phenomenological level, the similarities and differences inherent in these transitions. Key considerations include the determination of sensitive parameters of the transition rate, the potential for reversibility, and the stochastic nature of these processes.

It's important to note that this study does not seek to quantitatively address the actual historical transitions or delve into the detailed mechanisms leading to abstract models. Alternative methodologies, such as agent modeling, may later be employed to capture the intricate, disaggregated, and integrated dynamics among different stages.

In addition to the level of detail, another dimension of the model involves its characteristics. Yacov Haimes (2004) identified four characteristic properties for classifying models: 1) Aggregation: lumped (group) or distributed (individual); 2) Time dependence: static or dynamic; 3) Linearity: linear or non-linear with feedback loops; and 4) Determination: whether the system is deterministic or stochastic.

System dynamics models provide a means to explore the aggregate, dynamic, non-linear, stochastic nature of processes, facilitating an understanding of phenomenology (Forrester 1968). Recent applications of system dynamics and related agent modeling have contributed to comprehending historical transitions and dynamics within states during periods dominated by agricultural economies, shedding light on the development of peripheral states and their contribution to subsequent phases (Turchin 2003).

The modeling of these transitions occurs across multiple levels (Figure 1). Empirical logistic trend analysis models are suggested based on analyses of significant events, energy usage, and potentially hegemonic lifetimes. The subsequent step involves attempting to comprehend, at a phenomenological level, the similarities and differences in these transitions. Questions arise, such as when the transitions occur, what determines their rates, whether they are reversible, and how one transition contributes to the next. The proposition that a larger logistic trend is formed by embedded nested transitions suggests a rationale for the smaller, punctuated steps, akin to punctuated equilibrium in complex systems' growth or learning. This may indicate a system far from equilibrium, requiring dynamic equilibrium maintenance through oscillations, resembling an inverted pendulum, where a rod is balanced on an oscillating support (e.g., a pencil on a fingertip). Further insights may be gleaned from more detailed historical records and agent modeling (Christiansen and Altaweel 2006).



Agricultural Transition

Event	Transiton	Time Between
Sedentary Hunters	-15000	4000
Wild Cereal Tools	-11000	2000
Villages	-9000	500
Plant Domectication	-8500	500
Animal Domestication	-8000	1000
Pottery	-7000	1500
Chiefdom	-5500	1500
Metal Tools	-4000	

Figure 1. Various types of models that could be used to understand historical transitions include complex detailed models (right) and system dynamics models (left) that capture key processes in the transition. In this paper, the focus is on empirical rate of events (top) during the transition to determine a midpoint and duration of the transition. Then an analogy (bottom) to a physical model is suggested to help understand the qualitative aspects of the transition.

Geographical factors

The transitions from the stages of hunter-gatherers, agricultural societies, early civilizations, market development, industrialization, and sustainable societies are explored with models to demonstrate the unique aspects of each transition. Topics include land-pressures, economies of scale, suppressed growth, and technological substitution for raw resources.

This study first uses empirical analysis of the transitions by focusing on the rate of important events in the transition. Then an analogy to a physical model is suggested that captures some of the qualitative features of each transition. This study does not attempt to quantitatively address the actual historical mechanisms. Other modeling methods, such as system dynamics models and agent models, might be later used to capture the detailed, disaggregated, and integrated dynamics among the phases.

The transition of a population from one lifestyle to another can be caused by movement from one group to another motivated by various factors (Glotzl 2023). This simple system dynamics model has the general form shown at the top of Figure 2. Another mechanism is a differential growth rate between the two populations, shown at the bottom of Figure 2. These two transitions are often seen as an innovation diffuses spatially, with the first diffusing the innovation through other cultures whereas the second demonstrates the overwhelming growth of the group using the innovation. While diffusion is known to be rather slow, with the distance of the spatial diffusion front growing as the square root of the duration, when there is also growth, the combination of growth and diffusion leads to a front that progresses at a nearly linear rate, as has been observed in the diffusion of agriculture in Europe from the southeast to the northwest.

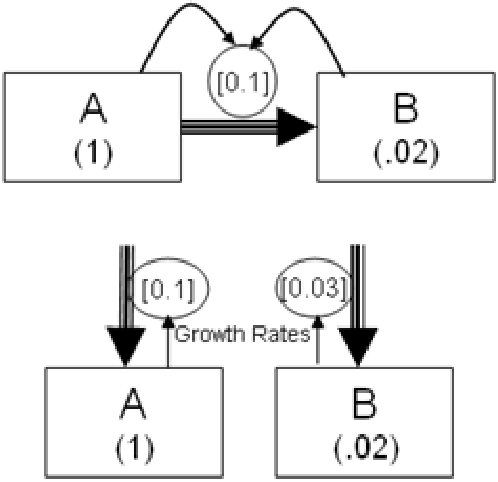


Figure 2. Two ways the prominent lifestyle can transition between two groups: through movement and adoption (top) or by differential growth rates between the two groups (bottom),

Various qualitative, narrative explanations have been suggested for other phases of historical transitions. Many of these transitions still have puzzling aspects such as the early transitions from hunter-gatherer to agricultural based society in which the average work day went from a few hours to at least triple that value (Diamond 2005). Another puzzle that has collected much attention is the explanation of the emergence of the scientific and industrial revolution first in Europe despite many individual similar discoveries previously in other regions (Goldstone 2009).

In a broader context, recent analysis of important events in Big History has shown a logistic trend (Modis, Panov). It was suggested that the overall logistic trend is composite, formed by nested logistic growth in discrete learning phases (LePoire 2015). Discussion has also included comparing this process to evolution of a complex adaptive system with the intensity of energy extraction as a driving parameter (Chaisson 2004; Fox 1988; Marchetti 1980; Jantsch 1980). Previous realizations of a central role of resources and complexity in societal evolution were made by White (1959) and Tainter (1988, 1996). The transitions between hunter-gatherers, agricultural societies, and early civilizations are explored with physical analogies to demonstrate the unique phenomenological aspects of each transition. Topics include land-pressures, economies of scale, and risk reduction.

Exploring Two Historical Transitions with Analogies, Empirical Evidence, and System Dynamics Modeling

Transition to Agriculture

What caused the transition from a relatively leisurely hunter-gatherer lifestyle to the more work-intensive agricultural lifestyle? It might not be exactly clear (Wiessner 2022), but we do know that all hunter-gatherer societies did not take the path to agriculture even when it was known as an option. For example, some northwestern Native American tribes continued a hunter gatherer lifestyle based on the quite abundant salmon, although due to the resources, they could remain in villages year round.

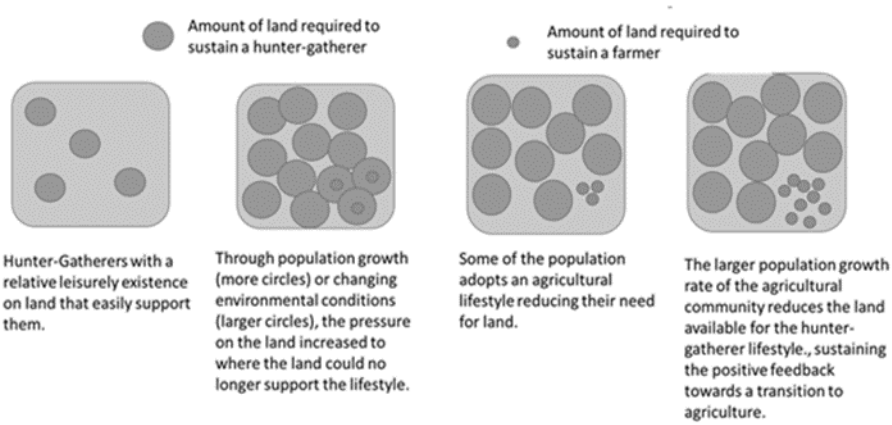
Perhaps, as long as good conditions continued, the hunter-gatherer lifestyle was adequate. As the population density of hunter-gathers slowly increased, competition (pressure) increased for land. With the greater stress on the natural resources, environmental conditions, such as drought, might reduce the land's productivity. Supplemental intermediate strategies such as slash-and-burn and swidden agricultural were developed. Agricultural land can support many more people than a hunter-gatherer society although it requires more work such as clearing, plowing, planting, nurturing, harvesting, selecting, and storing. The agricultural process also tended to encourage a more stationary existence since more investment was required to prepare the land and securely store food and tools.

A hunter-gatherer society could maintain small population growth through techniques such as delayed weaning. In agricultural communities, however, larger families were desired since some jobs were menial and could be performed by younger children. The pressure from these larger agricultural families further increased the competition for land in a positive feedback loop towards coalescence into agricultural communities. This process is similar to a phase transition from a gas (hunter-gatherers) to liquid (farmers) under increased pressure (Figure 3). This dynamic forms the basis of this logistic transition model to agriculture.

The model has two distinct populations of hunter-gatherers and farmers. Both compete for the land resources, although the farmers require a much smaller (e.g., a tenth) land area per person to support their lifestyle. If the population density is low, most people would continue the easier work of the hunter-gatherer lifestyle. This population grows slowly over thousands of years. Eventually, larger populations require most of the local area (which may be diminished due to land loss due to environmental or natural causes). The effort to live on such a densely populated area increases due to competition for the limited resources (e.g., wildlife). A few hunter-gatherers might try new approaches to secure food. As agriculture knowledge grows, eventually some people will settle down as farmers. However, this agricultural lifestyle is able to feed more people and use the children at an earlier age, increasing the population growth rate. This tends to propagate the lifestyle by increasing the competition for land (land pressure) which causes more hunter-gatherers to switch to farmers. Therefore, the transition continues towards agriculture with the important factors driving the transition being the relative land pressure and growth rates.

Evidence of intermediate events can be used to estimate the duration and midpoint of the transition. A list of important events in during various development phases might be constructed and analyzed corresponding to logistic (or learning) pattern (Table 1 and Figure 4). For example, Diamond (2005) discusses some important events in the transition from hunter-gatherer to agriculture. If each event is treated as being equally important, then this rate of events can be used to form a logistic curve. What one expects from this logistic pattern is a slow rate of events (discoveries) early in the transition process, followed by a quicker discovery rate, with the quickest rate at the inflection point halfway through the transition. Then a another slower phases of discoveries follows, near the end of the transition. The beginning of the transition was about 15,000 years ago with the exploration of sedentary hunters. The inflection point was about 9,000 years ago (7,000 BCE), with forms of plant domestication. The last major event putting the transition over 90% was the introduction of metal tools at about 5,000 years ago (3,000 BCE). The duration of the transition from 10% to 90% was about 9,000 years.

As the population density increased, pressure was placed on land resources to return higher yields. Supplemental intermediate strategies such as slash-and-burn and swidden agricultural were developed. Agricultural land can support more people than a hunter-gather society although it requires more work. A hunter-



Hunter-Gatherers with a relative leisurely existence on land that easily support them.

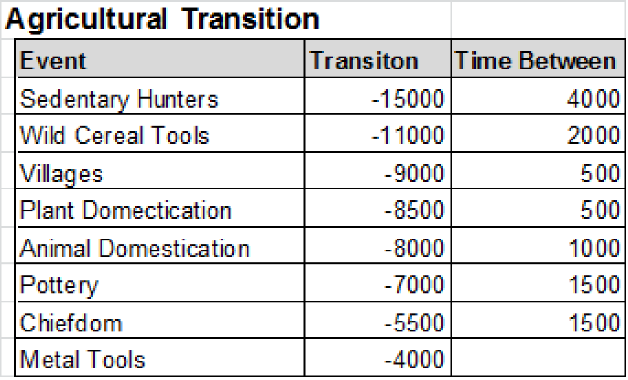
Through population growth (more circles) or changing environmental conditions (larger circles), the pressure on the land increased to where the land could no longer support the lifestyle.

Some of the population adopts an agricultural lifestyle reducing their need for land.

The larger population growth rate of the agricultural community reduces the land available for the hunter-gatherer lifestyle., sustaining the positive feedback towards a transition to agriculture.

Figure 3. Analogy of transition to an agricultural lifestyle based on land pressure leading to condensation into smaller but more intensive units.

gatherer society could maintain small population growth through techniques such as delayed weaning. In agricultural communities, however, larger families were desired since some jobs were menial and could be performed by younger children, thus reducing the work of the parents. The pressure from larger families further increased the population pressure resulting in a positive feedback loop. Thus the society coalesces into agricultural communities similar to a phase transition from a gas to liquid under increased pressure. This dynamic forms the basis of this logistic transition model to agriculture.



Agricultural Transition

Event	Transiton	Time Between
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Villages	-9000	500
Plant Domectication	-8500	500
Animal Domestication	-8000	1000
Pottery	-7000	1500
Chiefdom	-5500	1500
Metal Tools	-4000	

Table 1. Events in the Neolithic agricultural revolution based on Diamond (2005).

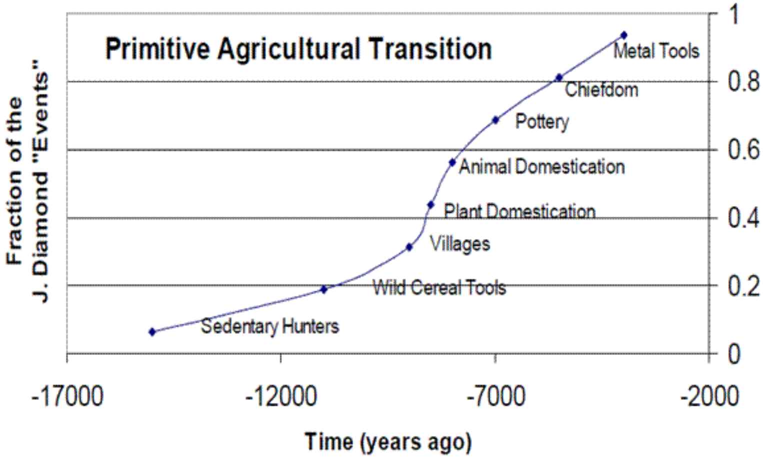


Figure 4. Logistic Trend of major events in the transition to primitive agricultural societies. Top: list of events from Jared Diamond. Bottom: Plot of rate of innovation assuming each event is equally important.

The model has two groups-hunter-gatherers and farmers (Figure 5). Both compete for the land resources, although the hunter-gathers require 10 times the amount of land per person to support their lifestyle. If the pressure is low, the easier work of the HG lifestyle gains converts, although with larger populations (or events that cause loss of land due to environmental or natural causes) a few may switch at least temporarily to an agricultural lifestyle. However, the agricultural lifestyle is able to feed more and use the children at an earlier age, tends to propagate the lifestyle by increasing the pressure. Therefore, the transition continues towards more farmers with the important processes which determine the transition rate being the land pressure and the relative growth rates.

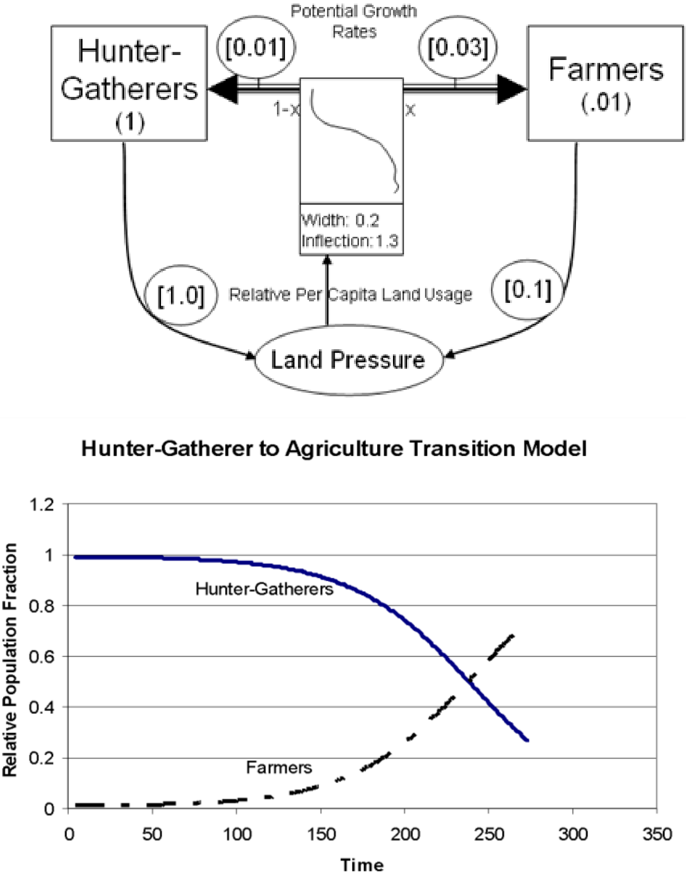


Figure 5: Top: Simple system dynamics model based on land pressure from slower growing hunter-gatherers and quicker growing but more intense farmers. Bottom: simulation results showing transition between populations.

Transition to Civilization

The development of cities around agricultural communities happened independently at a few location at various times in history, e.g., Mesopotamia, Nile, Indus, China, and Central America. The urban inhabitants exchanged protection, administration, and specialized crafts for surplus food from the rural communities. Administration included overseeing large public projects such as irrigation and food storage. The urban elite's role was to manage such risks as invasion and famine to ensure continued growth. This risk management was more important in areas where the population density was higher and natural disasters like floods and famine were more frequent. Decisions to centralize or decentralize organizations remains a key current issue and is dependent on complex considerations of the return on scale of various processes. The exploration and learning in this transition during the ancient and classical civilizations led to one of the largest and centralized empires based around a large city- the Roman Empire where about 20% of the population was either an urban dweller or in the military (Ponting 2007). However, its highly centralized nature led to dependence on dynamic growth for capturing new area and sources of labor to support the system.

The transition from agriculture villages to hierarchical civilizations is modeled with increasing economies of scale. That is as the city becomes larger the relative cost to the dwellers becomes less expensive. The agriculture villages were more susceptible to natural risks such as drought and flooding, which reduce their population growth. A hierarchical civilization allowed a management of food storage and mitigation of natural impacts with such tools as irrigation. The benefit of this investment in the administration and resource collection would be the capability to be more resilient when natural disasters occurred. Later as civilizations became more prevalent, war and diseases would also be added to the natural disasters. The impact of natural disasters would be larger near the more marginal lands. While at first, the natural river systems of Egypt and the Fertile Crescent provided suitable conditions, later civilizations further spread with the introduction of new technologies based on better materials such as bronze and iron.

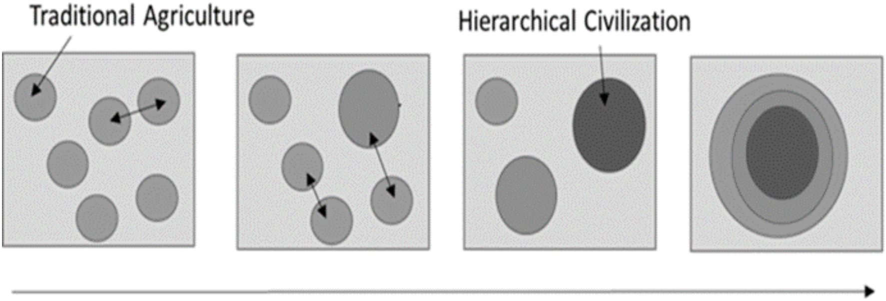
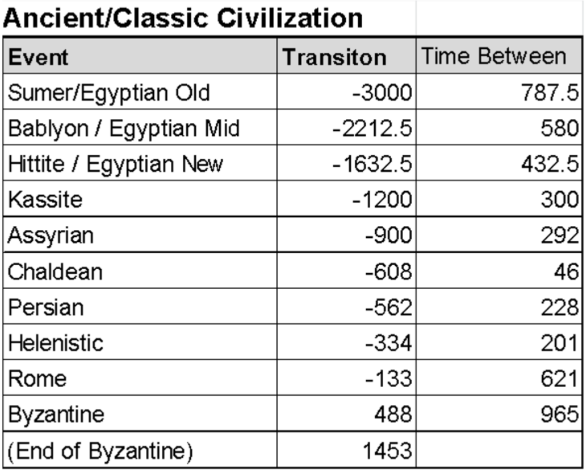


Figure 6. Consolidation model of civilization growth. As agricultural density grows, risk increase with the use of marginal lands and conflicts. A way to mitigate these risks is by forming a hierarchy to organize and distribute. The overhead needed for a hierarchy is smaller (on per person basis) with larger sizes (forming an economy of scale).

This conceptual model based on economies of scale of specialized management of risks is portrayed in the Figure 6. The transition to new levels of civilization proceeds when the mitigation of risks allows for larger average growth. Positive feedbacks arise from the relative military power of the more centralized state.

The sequence of dynastic (or national) durations from Mesopotamia and Egypt is shown in Table 2 and Figure 7. The process starts at about 3,000 BCE with early civilizations of Ur and Egypt. Empires rise and fall through learning processes such as incorporating new technologies, government organization, coordination of land and water rights, and developing military defenses. The dynastic duration tends to shorten in time before the midpoint inflection. This inflection, near 600 BCE, is near the collapse of many Bronze Age civilizations which occurred during the Greek Dark Ages. This inflection point is also near the middle of the Axial Age as Jaspers (1953) described it as "an interregnum between two ages of great empire, a pause for liberty, a deep breath bringing the most lucid consciousness." After this inflection point, ideas and technologies, such as iron working, were developed, and the duration of the major empires began to lengthen again leading to the Roman Empire and its direct related civilization the Byzantine Empire ending at about 1,000 AD. Both these empires were still built around one large city, Rome and Byzantium (Constantinople). However, while technology led to many infrastructure developments (such as water systems, ports, buildings and roads), the major energy input was based on agriculture with dependence on slave-based labor (Ponting 2007).



Ancient/Classic Civilization

Event	Transiton	Time Between
Sumer/Egyptian Old	-3000	787.5
Bablyon / Egyptian Mid	-2212.5	580
Hittite / Egyptian New	-1632.5	432.5
Kassite	-1200	300
Assyrian	-900	292
Chaldean	-608	46
Persian	-562	228
Helenistic	-334	201
Rome	-133	621
Byzantine	488	965
(End of Byzantine)	1453	

Table 2. Leading Ancient and Classical States (Bowden 2002).

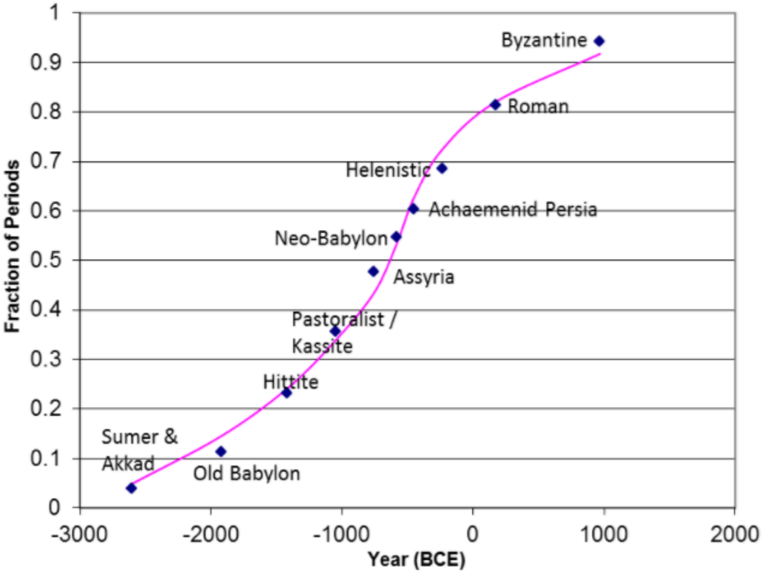


Figure 7. The transition through early civilization (ancient and classical) based on the duration of leading states Top: sequence of leading Mesopotamian states. Bottom: Plot of rate of innovation assuming each state is equally important.

A basic logistic systems dynamics model (Figure 9: Top) is altered with the conversion rate and direction between the populations being dependent on a stochastic centralization need. That is the farming villages would feel the full impact of the risk, e.g., flood, draught, pests, or war, but the civilization based on farming would have the impact mitigated by centralized actions such as irrigation, food preservation and storage, and defense. This stochastic impact is is the product of the civilized population and a balanced random number (-1 to 1). Note that the rate constant in the logistic equation, k, has an average value of zero. This means that the modeled transition is reversible, e.g., if there are few random impacts then the farming villages would be on average more productive. So therefore, the result is dependent on the rate of the random impacts. Figure 9 (bottom) shows one such stochastic transition, where the movement from the villages to the agricultural civilization is not smooth.

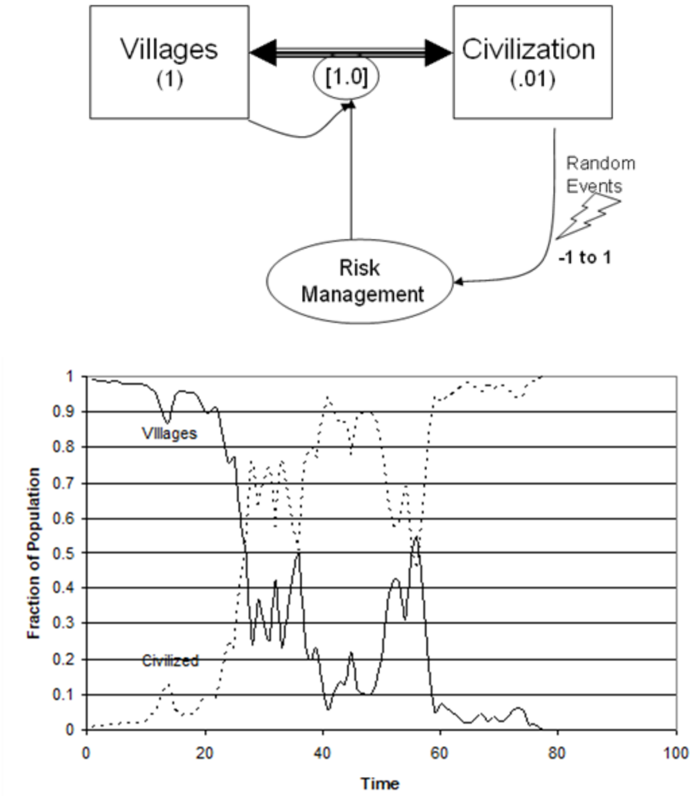


Figure 8. Top: Simple system dynamics model based on risk reduction provided by civilization overhead. Bottom: One of the stochastic simulation results showing transition between populations.

Discussion of further approaches to other historical transitions

A synthesis of previous studies has indicated an accelerated structure of history on Earth through the evolution of life, humans, and civilizations (LePoire 2023). The periods identified in this progression are consistent with traditional historical timelines in the geological, archeological, and civilization studies. Approximately six distinct phases emerged after the hunter-gatherer stage: early agricultural, early civilization, market development, capitalism, industrialization, and sustainability (Figure 9). The transitions between these phases occurred at intervals of approximately 15,000, 5,000, 1,500, 500, 150, and 50 years ago, revealing an accelerating pace with each successive phase and a notable threefold reduction in durations between consecutive phases. This tripling factor parallels changes in accelerating periods observed in natural biological evolution, cultural human evolution, and the technologically influenced revolutions in human history (LePoire 2015). The catalytic characteristics of technology innovations were a made driver in these transitions (Ayres 1989).

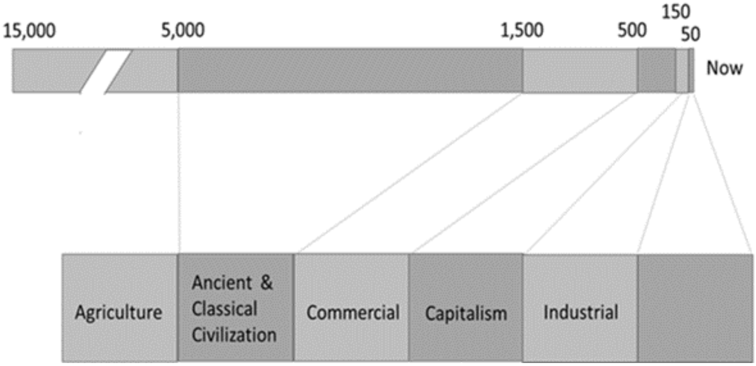


Figure 9. Timeline of historical transitions displayed on a linear time scale (top) and logarithmic scale (bottom). Since there is a factor of 3 reduction in the duration of the phases, each phase has the same width on the logarithmic scale.

Transition to Capitalism

The commercial markets and the trade of bulk items such as lumber and fish (instead of relying on mostly luxury goods), facilitated the use of machines and the introduction of capital formation often in the form of securing trading ships (Gimpel 1976, Lopez 1976). The components of the system such as stock markets, loans, banking, legal obligations, and insurance were established during the commercial market phase (Ferguson 2008). However, the independence of the European states meant that each state had its own way of experimenting with markets and relative interference. In 17th century the Dutch gained political independence from Spain leading to the Dutch golden age of art, commerce and exploration. The relative smallness of the country allowed for ideas to spread rapidly through the main financial center of Amsterdam. They also participated in the protestant reformation and also the scientific revolution with the likes of Huygens and van Leeuwenhoek.

While the riches began to accumulate in the Netherlands during their Golden Age with the arts and culture, other countries followed but on a larger scale. The English and Dutch had major naval battles to determine primacy in trade and economic development. The English established themselves as leaders after their civil war and instability by inviting the Dutch king to be their own in the Glorious

Revolution of 1688. England's population at the time was roughly twice the Dutch population. This pattern seemed to continue that leadership would pass after about a century to a state that was twice as large in population. This included the transition to the full United Kingdom (which included Scotland and Wales) in the 19th century and then to the U.S. There might be one or two possible future transitions (LePoire 2010). The pattern with the 4 transitions over the 400 years, suggests a midpoint at about 1800.

The analogy for this growth of capitalism is the growth of an individual fertilized egg cell during development to a multicellular organism. This pattern in the growth of capitalism is complicated by the necessity for a sequence of transitions to larger countries. The larger countries can supply larger markets and more complex infrastructure. This infrastructure includes not only the physical items such as roads and communications but also the social organizations such as governments and laws. Both cells and economic leadership transition by splitting on a periodic bases (cells: about a day; capitalist leadership about every 100 years). Another difference is that the biological growth is done without addition of any new material (for up to 16 cells) but in the capitalistic leadership transition, the nations grow between the transitions.

Current Transition

The current transition is towards a sustainable civilization where energy, population, and technology are balanced. The transition is complicated by the need to solve the current problems without creating overwhelming new ones within the context of rapidly changing technology (Homer-Dixon 2006, Ausubel 1996). For example, raising education and health of many people, especially women in developing countries, temporarily increases resource use through improved quality of life before the population growth rates stabilize. If the transition progresses too slow, the resources will not be concentrated enough and the solutions will not be found. If the transition goes too fast, the unresolved unintended problems will accumulate.

The "burnout" or sustainability model is known within many communities including ecology. Transitions in predator-prey models sometimes exhibit the "J-Curve" where the transition starts going through the characteristic S-Curve but does not stabilize at the higher level but instead collapses to a lower level. This is indicative of fueling the initial growth on some unsustainable resource.

An analogy is made between the transitions to a sustainable society to that of launching a rocket into orbit (LePoire 2018). A rocket, once launched, needs to reach a critical velocity and height before obtaining a sustainable orbit. Once a stable orbit is attained, there are many further beneficial options such as space observations or facilitating further space exploration. The basis for the analogy is that there are two stationary states for the rocket- the ground and a stable orbit.

The ground is analogous to the historical situation of a society based on traditional solar energy for crop growth, warmth, wind, and water. The stable orbit is analogous to an improved situation of an advanced society with more freedom, comforts and fulfillment, which is also stable through technologically capturing a larger fraction of the solar energy (or supplementing it with nuclear fission or fusion).

Table 3. Summary of the six transitions and their analogies presented in (LePoire 2019).

Transition	Approx. Beginning Point	Analogy	Parameters	Characteristics
Agriculture	13,000 BCE (15,000 ya)	Gas to Liquid Phase transition with increased pressures.	land pressure	Often not reversible
(Ancient and Classical) Civilization	3000 BCE (5,000 ya)	Centralize / decentralize Insurance model based on return of scales	benefits of centralization	Stochastic and reversible depending on random impacting events
Commercial Market	500 (1500 ya)	Prairie ecosystem sustainability	fractionation	Stochastic competition hindering further centralization
Capitalism	1550 (450 ya)	Early growth of an organism from one cell to many.	Division rate, rate of growth	Greater specialization requires larger population
Industrial	1850 (160 ya)	Critical innovation rate model	Exogenous innovation introduction rate	Stochastic and reversible due to information loss after innovation
Sustainable	1960 (50 ya)	Rocket launching model- consumes fossil fuel in attempt to reach sustainability (orbit).	technology substitution ability, demographics transition rates	Irreversible due to non-renewable resources

It is not clear if society's transition to energy sustainability (the metaphorical stable orbit) will be completed successfully. In this analogy, it is not at all clear which plan we should follow towards sustainability since we really do not know the fundamentals that any rocket engineer would know. Such information would include the weight of the rocket, the efficiency of the engines, the amount of fuel, the speed necessary to get into orbit, and the height of the orbit such that the atmosphere is negligible.

A rocket launch can crash from loss of stability, fuel tank explosion, too slow acceleration leading to inefficient use of fuel, too much acceleration damaging engines. The rocket might also heat up too much when going through the atmosphere or if the orbit is too low. The rocket might not orient correctly for a stable orbit. Another failure would be for the rocket to enter a stable orbit but lose the capability to support humans, e.g., buildup of carbon dioxide as started on the ill-fated Apollo 13. For each of these there are corresponding analogies in the transition to an advanced sustainable society. For example, the incentives might not be correct to guide us towards stability, the transition might be too slow (burning fossil fuels but making too little progress) or too fast (using technology that eventually is inappropriate or inefficient).

Summary

A topic of current discussion concerns the rate of technological progress, energy usage, and social change. One contribution to this discussion is historical analysis of important historical transitions. These transitions include development from hunter-gathers, to farmers, to civilizations, to market development, and capitalism. The rate of important events within these transitions indicate potential logistic trends. This trend throughout historical civilizations continues the accelerating rate of biological and human evolution, which seems to be leading to a nearing inflection period (as some have called the singularity [Panov et al., 2020; Korotayev, 2020]). This growth trend might also be viewed as a behavior exhibited by a complex adaptive system. As these systems develop further from equilibrium towards critical states, the systems spontaneously may bifurcate into two potential discrete states. The growth between the bifurcations might exhibit recursive logistic growth. The formation of a larger logistic trend by embedded nested transitions might be interpreted as a form of punctuated equilibrium. It has been suggested that energy usage might be the driving parameter for this generalized evolution.

References

Ausubel, Jesse. H. 1996. "Can technology spare the earth?" *American Scientist* 84 (2): 166-178. http://www.jstor.org/stable/29775636.

Ayres, Robert. 1989. *Technological Transformations and Long Waves*. RR-89-1, International Institute for Applied Systems Analysis, Laxenburg, Austria. https://pure.iiasa.ac.at/3225

Bowden, Hugh. 2002. *Ancient Civilizations*. Barnes & Noble.

Bowles, Samuel, Jung-Kyoo Choi. 2019. "The Neolithic Agricultural Revolution and the Origins of Private Property" *Journal of Political Economy* 127 (5): 2186 - 2228. https://doi.org/10.1086/701789.

Chaisson, E. 2004. "Complexity: An energetics agenda: Energy as the motor of evolution." *Complexity* 9 (3): 14-21. https://doi.org/10.1002/cplx.20009.

Christian, D., C. S. Brown, and C. Benjamin. 2014. *Big History: Between Nothing and Everything*. McGraw Hill Education, NY, NY.

Christiansen, J. H., and M. Altaweel. 2006. "Simulation of natural and social process interactions: an example from Bronze Age Mesopotamia". *Social Science Computer Review* 24 (2): 209-226. http://dx.doi.org/10.1177/0894439305281500.

Costanza, R., L. Wainger, C. Folke, and K-G. Mäler. 1993. "Modeling complex ecological economic systems: Toward an evolutionary, dynamic understanding of people and nature". *BioScience* 43 (8): 545–555. http://dx.doi.org/10.1007/978-1-4612-4018-1_15

Diamond, Jared M. 2005. *Collapse: How Societies Choose to Fail or Succeed*. New York, Viking.

Ferguson, Niall. 2008. *The Ascent of Money: The Financial History of the World*. Penguin.

Fewster, Helen. 2016. *Big History*. DK / Penguin Random House.

Forrester, Jay W. 1968. *Principles of Systems*. MIT Press, Cambridge, Massachusetts.

Fox, Ronald. F. 1988. *Energy and the Evolution of Life*. New York, W.H. Freeman.

Gimpel, Jean. 1976. *The Medieval Machine: The Industrial Revolution of the Middle Ages*. Barnes and Noble.

Glötzl, Erhard. 2023. *The Evolutionary Theory of Everything: From the origin of life to the market economy*. Independently published on Amazon.

Goldstone, Jack. A. 2009. *Why Europe?* McGraw Hill, New York, N.Y.

Gunderson, Lance H., and C. S. Holling. 2002. *Panarchy: Understanding Transformations in Human and Natural Systems*. Washington D.C., Island Press.

Haimes, Yacov Y. 2004. *Risk Modeling, Assessment, and Management*. Wiley Interscience.

Homer-Dixon, Thomas F. 2006. *The Upside of Down: Catastrophe, Creativity, and the Renewal of Civilization*. Washington, Island Press.

Jantsch, Erich. 1980. *The Self-Organizing Universe: Scientific and Human Implications of the Emerging Paradigm of Evolution*. Oxford, UK: Pergamon.

Jaspers, Karl. 1953. *The Origin and Goal of History*. Bullock, London: Routledge.

Korotayev, Andrey. 2020. "The 21st century Singularity in the Big History perspective. A re-analysis." In *The 21st century Singularity and global futures. A Big History perspective,* edited by Andrey Korotayev and David J. LePoire, 19-75. Cham: Springer. https://doi.org/10.1007/978-3-030-33730-8_2

LePoire, David. J. 2010. "Long-term Population, Productivity, and Energy Use Trends in the Sequence of Leading Capitalist Nations." *Technological Forecasting and Social Change* 77 (8): 1303-1310. http://dx.doi.org/10.1016/j.techfore.2010.05.003

LePoire, David. J. 2015. "Interpreting Big History as Complex Adaptive System Dynamics with Nested Logistic Transitions in Energy Flow and Organization." *Emergence: Complexity & Organization* 17 (1): 1 E. doi: 10.emerg/10.17357.dbe7c8d6fae7f082c4f33c5b35df8287

LePoire, David. J. 2018. "Rocketing to Energy Sustainability." *Journal of Big History* 2 (2): 103 – 114. http://dx.doi.org/10.22339/jbh.v2i2.2304

LePoire, David. J. 2019. "Exploration of Historical Transitions with Simple Analogies and Empirical Event Rates." *Journal of Big History* 3 (1): 1-16. http://dx.doi.org/10.22339/jbh.v3i2.3210

LePoire, David J. 2023. "Synthesizing Historical Research Leads to a Simple, Compatible, and Extensible Big History Framework and Periodization." *Journal of Big History* 6 (3): 35-47. https://doi.org/10.22339/jbh.v6i3.6304

Lopez, Robert S. 1976. *The Commercial Revolution of the Middle Ages, 950-1350*. Cambridge University Press.

Marchetti, Cesare. 1980. "Society as a Learning System: Discovery, Invention, and Innovation Cycles Revisited." *Technological Forecasting and Social Change* 18: 267-282. https://doi.org/10.1016/0040-1625%2880%2990090-6

Panov, Alexander, David J. LePoire, and Andrey Korotayev. 2020. "The 21st century Singularity in the Big History perspective. An overview." In Korotayev, A. and D.J. LePoire (eds) *The 21st century Singularity and global futures. A Big History perspective*, edited by Andrey Korotayev and David LePoire, 1–18. Cham: Springer. https://doi.org/10.1007/978-3-030-33730-8_1

Ponting, Clive. 2007. *A New Green History of the World: The Environment and the Collapse of Great Civilizations*. New York: Penguin Books.

Tainter, Joseph A. 1996. "Complexity, Problem Solving, and Sustainable Societies." In *Getting Down to Earth*, edited by R. Constanza, O., Segura, and J. Martinez-Alier, 61-76. Washington, D.C.: Island Press.

Tainter, Joseph A. 1988. *The Collapse of Complex Societies*. Cambridge University Press.

Turchin, Peter. 2003. *Historical Dynamics: Why States Rise and Fall*. Princeton, Princeton University Press.

Volk, Tyler. 2017. *From Quarks to Culture: How We Came to Be*. Columbia University Press.

Wiessner, Polly. 2022. "Hunter-gatherers: perspectives from the starting point". *Cliodynamics SI:* Leading Scholars of the Past Comment on Dawn of Everything. Review 3, 1–6. https://doi.org/10.21237/C7clio0057263

White, Leslie. 1959. *The Evolution of Culture*. McGraw Hill Publishers.