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Toward Cliodynamics – an Analytical, Predictive Science of History

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This article responds to those who think that a science of history is in principle impossible. First, I tackle the issue of prediction and point out that it is not limited to forecasting the future. Scientific prediction is also (an much more usefully) employed in empirical tests of scientific theories. Next, I switch from conceptual to empirical issues, and review evidence for general empirical regularities. I also discuss some recent examples of using scientific prediction in testing theories about historical dynamics. I conclude by pointing out that we now have the right quantitative tools and, even more important, a growing corpus of historical data for testing theories. An analytical, predictive history, or *cliodynamics*, is eminently possible.

Introduction

Philosophers have long debated whether history can be a science in the same sense that physics and biology are sciences. At the heart of the debate are two opposing views of history. Nineteenth century thinkers, such as Leo Tolstoy and Carl von Clausewitz (see Gaddis, this volume), believed that historical process was governed by some kind of general laws. Many French and English historians of the nineteenth century viewed history as a science [42]. Twentieth century historians such as Toynbee [31] proposed grand schemes to account for the rise, the flowering, and the decline of civilizations. A less ambitious (but in the long run more influential) effort by McNeill [17] is another example of an attempt to discern patterns in history.

During the second half of the twentieth century, however, the general opinion among philosophers and historians swung against the possibility of scientific history. For example, Karl Popper [18] argued that there is a qualitative difference between history and natural sciences. Historical processes are too complex and different in nature from physical or biological processes. Most tellingly, people have free will, while atoms do not.

Among the historians, research paradigms that modeled themselves on natural sciences were still popular in the 1960s and 1970s [43]. Perhaps the most influential of such research programs was the French Annales school of history. During these decades the new economic history, or cliometrics, briefly flowered in the United States [44]. However, in the 1980s historians

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repudiated these approaches. As one reviewer of an early version of this article wrote, "cliometrics went under by the early 1990s; our own quantitative historian was denied tenure in approximately 1996 (by that point, no one really cared about the subject or its application in history)." Instead history experienced its "linguistic turn" or "cultural turn" [44, 45].

The view that history is fundamentally different from natural sciences is the one widely held today by philosophers and the lay public alike. With the exception of a tiny minority (several of whom are represented in this volume) the historical profession has largely abandoned the search for general laws in history. This philosophical stance is very apparent in the views of prominent historians, for example, in "President's Columns", published by of Perspectives on History, where presidents of the American Historical Association express opinions on a wide variety of general topics confronting the historical profession. During the last decade (the 1999–2008 issues of Perspectives on History) there were at least three columns that discussed the role of general laws or theories in history [4, 10, 22]. The following quote appears to be a fair summary of the opinions of the three historians:

> After a century of grand theory, from Marxism and Social Darwinism to structuralism and postmodernism, most historians have abandoned the belief in general laws. We no longer search for grand designs and dialectics. Instead, we concentrate on the particular and sometimes even the microscopic (*microstoria*, as it is known in Italy) – not because we think we can see the universe in a grain of sand but because we have developed an increased sensitivity to the complexities that differentiate one society or one subculture from another. Kosovo is very different from the rest of Yugoslavia, to say nothing of Vietnam [4].

In my opinion, historians gave up on general theory too soon. The need for an analytical, predictive history remains acute if we wish to address such problems plaguing humanity as failed states and endemic civil wars [36]. On the other hand, there is no question that the bankrupt paradigms mentioned by Darnton, from Marxism to postmodernism, deserve to be abandoned. However, we now have better theories and approaches, which have profited from recent developments in nonlinear dynamics and complexity science.

It is possible that this new batch of theories will eventually end up on the same trash heap of history as Marxism and Social Darwinism. But I don't think so. My argument has two parts. First, I respond to those who think that a science of history is in principle impossible and discuss a broader notion of prediction that is not limited to forecasting the future. Next, I switch from conceptual to empirical issues, and review evidence for general empirical regularities. I also discuss some recent examples of employing scientific prediction in testing theories about historical dynamics. In the Conclusion I point out that we now have the right quantitative tools and, even more important, a growing corpus of historical data for testing theories. An analytical, predictive history, or cliodynamics, as I propose we call it, is eminently possible.

Is there a qualitative difference between history and natural sciences?

The issue of prediction

As mentioned above, one of the most influential arguments against scientific history was formulated by the philosopher Karl Popper. Popper's main point was that because the future course of human history is critically affected by the development of knowledge, and because future scientific and technological discoveries cannot be predicted, a predictive science of human history is in principle impossible.

There are additional reasons for why accurate forecasts about the future are difficult, or even impossible with real-life social systems. These reasons include such phenomena as the self-defeating prophecy and mathematical chaos (the latter of which was not yet appreciated when Popper wrote *The Poverty of Historicism*). However, the notion of *prediction* in science is not limited to forecasting the future. If it were, whole swaths of science would lose their status as scientific disciplines. The paradigmatic example is the weather, which cannot be forecast more than 7–10 days in the future, even though we perfectly well understand the laws of hydrodynamics underlying weather fluctuations. However, because the dynamical system governing weather is in a chaotic regime and our measurements of initial conditions are not infinitely accurate, long-term prediction of weather is impossible.

In fact, the future is in principle unpredictable. A high-school demonstration of the motion of uniformly accelerated objects, using an inclined plane, may go awry because an earthquake occurs during the experiment. The chance of such an event is rather small, but it is not zero. In social life rare events with huge consequences, the "Black Swans" of Nassim Nicholas Taleb [28], occur with greater frequency than in purely physical applications. The difference, however, is quantitative, not qualitative. Bridges collapse, space shuttles explode, and hurricanes strike from seemingly blue skies. However, we do not decide, on the basis of such prediction failures, that there are no laws of physics.

Prediction is an inherent part of science, but not in the narrow sense of forecasting the future. *Scientific prediction* (to distinguish it from the common usage, which is closer in meaning to "prophecy") is used in empirical tests of scientific theories. Scientific prediction inverses the logic of forecasting: whereas in making forecasts we assume the validity of the underlying theory and want to know what will happen to observables, in a scientific prediction exercise we want to use the degree of match between observables and predictions to infer the validity of the theory (Turchin 2006b). Because no theory makes perfect predictions, we typically want to compare the match between predictions and data for two (or more) theories.

Scientific predictions may be, but do not have to be, about the future. In many historical sciences, such as geology and evolutionary biology, making predictions about the future is impractical. Strong predictions should address "out-of-sample" data, that is, data that had not been used to develop the theory that is tested. Thus, it is a perfectly valid exercise to make retrospective predictions, or "retrodictions" [13]. Historical experiments (by an *experiment* I mean a planned comparison between predictions derived from two or more theories and data) may focus on making predictions about the state of a certain variable for a certain past society, which is not known at the time when the predictions are made. For example, Theory #1 says that the variable should be decreasing, while Theory #2 says, no, it should be increasing. We then ask historians to dig through the archives (or, perhaps, archaeologists to literally dig up the data), and determine which of the theories is closer to the truth. As more such experiments are conducted, and if one of the theories consistently yields predictions that are in better agreement with empirical patterns than the other(s), our degree of belief into the better performing theory is consequently enhanced. I will discuss in later section some examples of such experiments in historical applications.

History and biology

Karl Popper held strong views about what constituted science. In addition to history, he also criticized evolutionary biology, which, in his view was not a real science, but at best "a metaphysical research program." Ultimately, his rejection of history and evolutionary biology was not due to logic or empirical evidence, but to ideology [2]. His personal experiences (he emigrated from his native Vienna in 1937 just in time to escape the Anschluss) made him into a life-ling opponent of totalitarian ideologies, such as Nazism and Marxism. The real targets of Popper critique were Historical Materialism and Social Darwinism, but somehow he ended up condemning whole fields of scientific enquiry.

Evolutionary theory, contrary to Popper, is today an established scientific discipline, and, in my opinion, the same will eventually happen to history. Actually, there are some interesting parallels between the state of history now and the state of biology in the nineteenth century, before the scientific triumphs of Charles Darwin and Louis Pasteur. The reigning theory in biology at that time was vitalism, a doctrine that the processes of life were not explicable by the laws of physics and chemistry alone. It was believed that biological entities contained a "vital spark" or "*élan vital*," which could not be studied with the methods of physics and chemistry.

Vitalism is now thoroughly discredited, but this does not mean that it was a silly theory for its times. Early scientists noted that substances seemingly fell in two general classes. An inorganic substance, such as a lump of gold, could be heated to the point where it changed its state (melted), but on cooling it returned to its original form. Organic substances, when heated, changed irrevocably. The process of heating seemingly expelled the vital force from such substances. The destructive effect of heat on the vital force was the reason why Pasteur had to design the famous "*col de cygne*" (swan neck) bottle to disprove the theory of spontaneous generation – his first experiments were criticized on the grounds that by boiling broth in closed bottles he destroyed the vital force needed for spontaneous generation of life.

Ultimately vitalism was discredited not because of critical experiments, such as that of Pasteur, but as a result of hard, and often mundane, work by myriads of biologists who consistently applied the scientific method to biological questions and eventually found that there was no need of a vital force to explain general regularities in their data. In the process biology transformed itself from the descriptive discipline that it was in the nineteenth century (just like history is today) to an analytical, explanatory, and predictive science of the twentieth century. Are there lessons for those of us who would like to achieve a similar transformation of history?

History and mathematics

One of the most important lessons is recognizing the key role of mathematics in the transition of biology from the descriptive to explanatory science (see also the article by Geoffrey West in this volume). It was mathematical reasoning that almost discredited Darwin's theory of evolution in the late nineteenth century. The dominant theory of inheritance in Darwin's time assumed that the offspring's traits were a blend of its parents' traits. Such blending inheritance destroyed genetic variation that was absolutely necessary for natural selection to work on. No genetic variation meant no evolution. When biologists discovered that the theory of blending inheritance was wrong, it was again mathematical modelers who established the firm logical foundation for the Neo-Darwinist Modern Synthesis during the 1930s.

One of the most striking examples of the value of mathematical models comes from the field of population dynamics. In 1924 Charles Elton published a paper entitled *Periodic fluctuations in the number of animals: their causes and effects*. After reviewing the population data on lemmings, hares, and mice, and considering various hypotheses that might account for periodic changes in their numbers, Elton concluded that these fluctuations must be due to climatic variations. What is remarkable is that Elton never considered the cause that we now know is one of the most common drivers of population cycles – the population interaction between predators and prey [32]. The reason is that it never occurred to him. In *Modeling Nature* the historian of science Sharon Kingsland [12] relates how two years later Julian Huxley walked into Elton's office and showed him an article by the Italian mathematician Vito Volterra that was just published in *Nature*. The article presented a simple mathematical model of predator-prey interaction, and showed that the outcome is population cycles of both species. Huxley, one of the founders of modern evolutionary biology, and Elton, often considered as the father of animal ecology, were very intelligent people. But it took a paper written by a mathematician, who knew nothing about real animals, to open their eyes to the possibility of predator-prey cycles.

A common objection to employing mathematical models in the study of historical dynamics is that social systems are so complex that any mathematical model would be a hopeless oversimplification without any chance of telling us interesting things about these systems. This argument gets it exactly wrong – it is because social systems are so complex that we need mathematical models. "Naked" human brain is not a bad tool for extrapolating linear trends, but it fails abysmally when confronted with systems of multiple parts interconnected with nonlinear feedback loops. This is probably why it took a mathematical model to point out that cycles are inherent in the interaction between predators and prey (and this is a very simple system, with just two interacting components). We need mathematical formalism to express our ideas unambiguously, and both analytical methods and fast computers to determine the implications of the assumptions we made.

Complexity: social and biological

It is undeniable that social systems are very complex, and have little resemblance to such paradigmatic success stories in physics as Newton's planetary motions. However, many objects in natural sciences are no less complex than human societies. Consider, for example, a temperate forest ecosystem. There is likely to be at least a dozen species of trees and shrubs and a hundred or more of herbs, forbs, and other smaller plants. There will be innumerable species of insects, mites, lower invertebrates, fungi, protozoa, and bacteria. All this life will be busy doing its thing around you; mice will scurry underfoot and birds will be singing in the branches. It is a horrible mess (or glorious complexity, depending on your point of view). How could it possibly give rise to any laws of nature? Yet it does.

Over the last century ecologists identified many kinds of empirical regularities in forest ecosystems. To continue with population cycles, almost every forest, especially those in boreal and temperate climatic zones, has a particularly voracious species of insect that periodically runs amok denuding trees of their foliage, or even killing them outright. These population cycles can be quite predictable. For example, the populations of the larch budmoth reach a peak in the larch forests of the Swiss Alps every 8.5 years [32]. The amplitude of these oscillations is remarkable – the population density in the trough is five orders of magnitude (100,000 times) lower than at the peak.

Somehow large-amplitude regular oscillations arise from the mess of nature in ecosystems. Why should the social systems be different? After all a social system consists of only one species. Of course people are not all the same – there are different social classes and professions, different religions and ethnic identities, and so on. Still, when we add together the different kinds of humans in an average historical social system (an agrarian state, for example), I doubt that the total would come anywhere near the number of species in an average ecosystem.

Empirical regularities

In the Second Afterword to *War and Peace*, Leo Tolstoy argued that in order to find laws of history, we should focus on large masses of people and not on individuals, no matter how important they seem (his example was Napoleon Bonaparte). If from the microchaos of molecular motions arise the laws of thermodynamics, and from interactions between individual lynxes and hares arise regular predator-prey cycles, then perhaps there may be general regularities characterizing the dynamics of human societies, even though the behavior of each person is unpredictable. In fact, we have already found a number of empirical regularities in historical social systems. Moreover, certain progress has been made in identifying general principles that may underlie these regularities. At least, it is now possible to point toward successful examples of scientific prediction in historical dynamics. I review three such "success stories" in this section.

A Striking Macrohistorical Pattern: Huge Empires Tend to Rise on Steppe Frontiers

What were the social mechanisms that held together huge historical empires? At present, we do not have a satisfactory theory accounting for the rise of such macrostates, with territories extending across millions of squared kilometers and populations numbering millions (or even tens and hundreds of millions). However, there are certain empirical regularities in the spatial and temporal distribution of "imperiogenesis" hinting that there may be general principles at play.

In a recent publication [38], I collected as many instances, as I could find, of historical "mega-empires" (defined as territorial states that controlled at the peak an area greater than one million square kilometers). I found 65 such polities for the agrarian period of human history (that is, before 1800). Over 90 percent of these empires were situated in, or next to the arid belt that runs through Afroeurasia, from the Sahara in the West to the Gobi in the East

(Turchin [34]: figure 1). The exceptions included the only empire in the Americas (Inca), one empire in Southeast Asia (Khmer), and three in Europe (the Roman and Carolingian empires, and perhaps Lithuania-Poland, although the latter expanded during the fourteenth century into steppe lands). Thus, there is a strong statistical association between proximity to steppe and the rise of megaempires.

1. Between the Shang era and the present, China has been unified fourteen times (some unifications were partial). All but one of these unifications (the Ming) originated in the North: eight from the Northwest, and three each from the North Central and the Northeast. In other words, with one exception all great unifying dynasties arose in the area right on the Inner Asian frontier of China. The other side of the frontier saw a succession of gigantic imperial confederations of such nomadic peoples as the Xiongnu, the Turks, and the Mongols.
2. Ancient Egypt was unified by native dynasties on four occasions: Early Dynastic (c.3100 BCE), Old Kingdom (2700 BCE), Middle Kingdom (2040 BCE), and New Kingdom (1570 BCE). In all four cases, unifying dynasties arose in Southern Egypt (in Hierakonpolis or Thebes). Furthermore, 5,000 years ago Southern Egypt was surrounded not by a lifeless desert, but by a grassy steppe inhabited by such pastoralist peoples as Nubians and Medjay. Towards the end of the first millennium BCE the steppe turned into desert, and from that point on Egypt never gave a rise to a native unifying dynasty, instead being ruled by a succession of foreign invaders. As in East Asia, the southern frontier of Egypt saw a succession of “mirror empires.” Starting with the Old Kingdom, and continuing even after Egypt lost its independence, Nubia was repeatedly unified under the empires of Kerma, Napata, Meroë, Nobadia, Makuria (Dongola), and Funj.
3. The Eurasian arid zone intrudes into South Asia from the northwest. Out of nine South Asian unifications (most partial, as they did not include India’s far south), five originated in the Northwest, three in the North, and one in the West. Despite the formation of numerous medium- and small-size states in other regions, no megaempires originated in the Northeast, Central, or Southern India.

In summary, in all these world regions (as well as others, such as Eastern Europe) empires originated on a steppe frontier, and only afterwards expanded into the agrarian hinterland. Thus, steppe frontiers appear to be very special places for imperiogenesis, places where very large territorial states are much more likely to arise than elsewhere. The pattern of association between steppe frontiers and mega-empire occurrence becomes particularly striking in regions that had a steppe frontier on only one side, as in the three cases listed above (and unlike Mesopotamia and Iran, which experienced steppe influences from multiple directions). The connection between steppe frontiers and mega-empires is not deterministic (because there are exceptions), but the statistical correlation is very strong.

Strong macrohistorical regularities suggest that the rise of any particular mega-empire was not a random result of a concatenation of unique events; general social mechanisms must have been at work. Building on the ideas of the fourteenth century thinker Ibn Khaldun [11], as well as contemporary anthropologists [1, 15], I have proposed a "mirror-empire" model as one common route to mega-empire [38]. This model postulates that antagonistic interactions between nomadic pastoralists and settled agriculturalists result in an autocatalytic process, which pressures both nomadic and farming polities to scale up polity size, and thus military power. In many cases, as happened repeatedly in China and Ancient Egypt, the end result of this process is the simultaneous rise of an agrarian empire and a nomadic imperial confederation on their respective sides of the steppe frontier. However, if the agrarian state does not have a deep hinterland to expand into, it may lose the scaling-up race to the nomadic polity, and is conquered by it. This was the typical dynamic in the Maghreb, so admirably described by Ibn Khaldun.

Secular cycles: linked oscillations in demographic, social, and political structures of agrarian societies

The pattern of population change is strongly affected by the scale at which it is observed. On a very long time scale of millennia population numbers increase at an accelerating rate, while on the time scale of years, several bad harvests in a row can cause a temporary dip in numbers, which is made up as soon as weather gets better. At the intermediate scale of decades and centuries the dominant pattern appears to be *secular cycles*: roughly century-long periods of sustained population growth followed by a similarly long period of population decline and stagnation [37]. For example, in Western Europe the thirteenth century was a period of vigorous population growth, while during the fourteenth and the first half of the fifteenth centuries population declined. The sixteenth century was another period of rapid growth, followed by the decline and stagnation of the seventeenth.

One possible explanation of this pattern of long-term population oscillations is offered by the demographic-structural theory [8, 31, 39]. First, population growth beyond the means of subsistence leads to declining levels of consumption and popular discontent. Second, and more important, sustained population growth also results in increasing numbers of aspirants for elite positions, leading to intra-elite rivalry and factionalism. A third consequence is persistent inflation, which causes a decline in real state revenues and a developing fiscal crisis of the state. As these trends intensify, the result is state bankruptcy and loss of military control; spiraling conflict among elite factions; and a combination of elite-mobilized and popular uprisings that lead to breakdown of central authority. In turn, political instability (urban riots, peasant uprisings, and full-scale civil war) results in population decline. Eventually, the balance between population numbers and the means of subsistence is restored, and another cycle can begin.

Various assumptions about dynamical feedbacks between key demographic-structural variables, such as population growth, elite overproduction, state strength, and political instability, have been investigated with formal mathematical models (Turchin [31], ch. 7; 35]). A typical dynamical pattern of association between population growth and political instability, predicted by these models, is coupled oscillations of population dynamics and political instability. Both variables cycle with the same period, but are shifted in phase with respect to each other, so that instability peaks during the periods of population decline (figure 1).

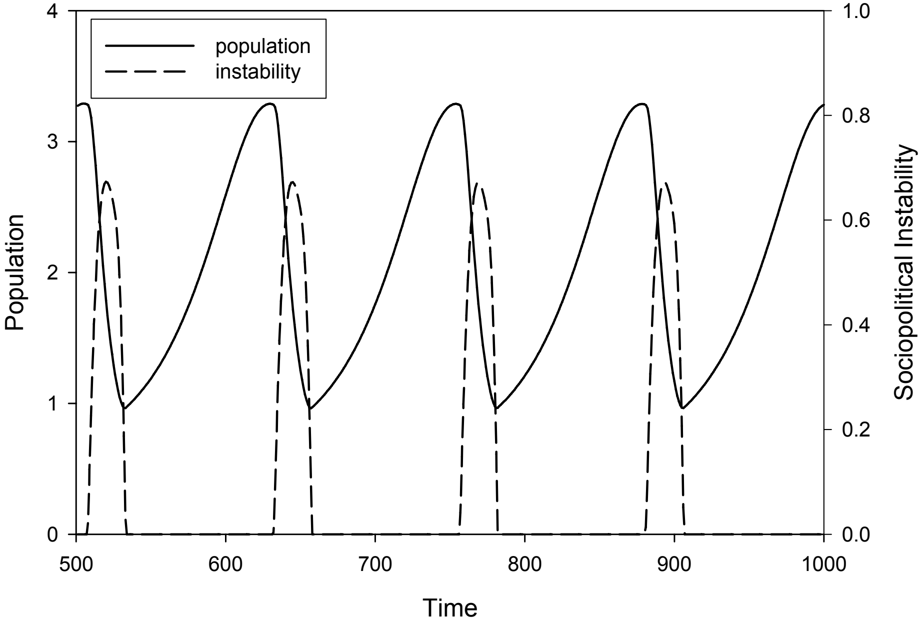


Figure 1. Linked population-instability oscillations predicted by a demographic-structural model (Turchin and Korotayev [35], eq. 8).

In real life, we do not expect to see smooth, perfectly periodic cycles. Historical societies are characterized by a much richer, more complex web of dynamical feedbacks than can be portrayed in mathematical models. Multiplicity of nonlinear feedbacks increases the probability that the dynamics will be chaotic, resulting in irregular, noisy-looking oscillations. Furthermore, social systems are affected by exogenous variables, such as climate fluctuations, that also generate erratic dynamics. Events at the microlevel, including acts of individual people, may percolate up and have macro-level consequences. Finally, and most importantly, our data on historical dynamics is often sparse and suffers from large amounts of observation noise. These complications must be taken into account when we look at real data. Yet, despite all these problems, we observe the basic dynamical pattern predicted by theory: linked oscillations with peaks of sociopolitical instability lagging behind population peaks (figure 2). This observation suggests that the demographic-structural model, indeed, captures an important aspect of the functioning of historical societies.

How can we design a general and quantitative test that goes beyond an eyeball comparison of predictions (figure 1) to the observed patterns (e.g., figure 2)? Given the limitations of historical data and the complexity of the dynamical pattern (variability in oscillation periods and phase shifts), we need to employ an appropriately coarse-grained procedure (see also the articles by Murray Gell-Mann and Geoffrey West in this volume). One possible approach works as follows. First, we identify the population growth and decline phases. Although quantitative details of population dynamics for historic societies are rarely known with any precision, there is usually a consensus among demographic historians about when the qualitative pattern of growth changed. Second, we count instability events (peasant uprisings, separatist rebellions, civil wars, etc) that occurred during each phase. Finally, we compare the incidence of instability events per decade between the two phases. Theory predicts that we should have much greater instability during population decline versus growth phases.

First, we apply this procedure to secular cycles in China (table 1). The test is conducted only for periods when China was unified under one dynasty. The empirical regularity is very strong: in all cases instability is greater during the declining, compared to growth phases (t-test: $P << 0.001$).

Next, we apply the approach to all seven complete cycles examined in Turchin and Nefedov [39] (table 2). The instability data were taken from such compilations as that of Sorokin [23], Tilly [29], and Stearns [27]. Again, the empirical regularity is strong and statistically highly significant (in all cases instability is greater during the declining, compared to growth phases; t-test: $P << 0.001$).

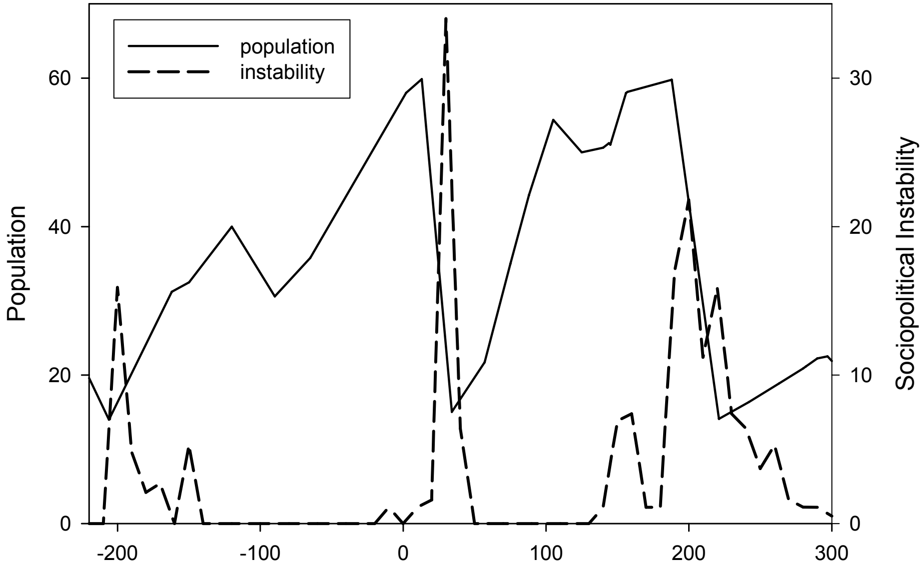


Figure 2. Population dynamics and sociopolitical instability in China from the Qin unification to the period of Three Kingdoms (220 BCE – 300 CE). For data sources, see Turchin ([31], p.164)

Table 1. Secular Cycles in Europe and China During the Last Millennium Compared to Global Economy Processes

European cycles	*Chinese cycles*	*Global Economy Processes*
Ottonian-Salian 920–1150	Northern Song 960–1127	Sung* Breakthrough 930–1190
Capetian 1150–1450	Mongol-Yuan 1200–1368	Nautical/Commercial Revolutions 1190–1430
Valois 1450–1660	Ming 1368–1644	Oceanic Trading System 1430–1640
Bourbon 1660–1870	Qing 1644–1911	Industrial Takeoff (1640–1850)

*A variant spelling of Song

Table 2. Instability events per decade during the growth and decline phases of the secular cycles surveyed in Turchin and Nefedov [39].

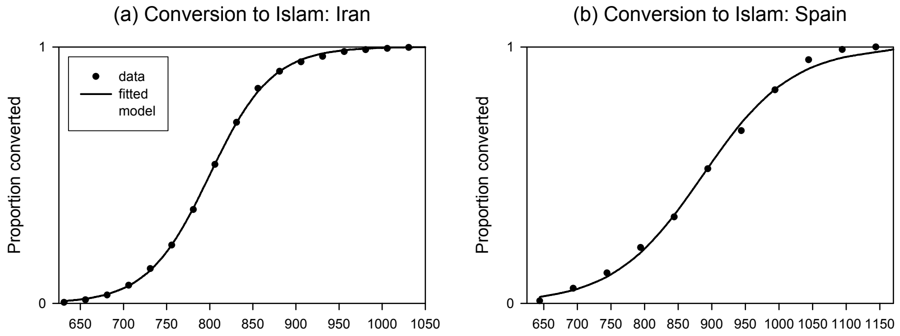
	Growth phase		*Decline phase*	
Secular Cycle	*years*	*Instability*	*years*	*Instability*
Plantagenet	1151–1315	0.78	1316–1485	2.53
Tudor	1486–1640	0.47	1641–1730	2.44
Capetian	1216–1315	0.80	1316–1450	3.26
Valois	1451–1570	0.75	1571–1660	6.67
Republican	350–130 BCE	0.41	130–30 BCE	4.40
Principate	30 BCE–165	0.61	165–285	3.83
Muscovite	1465–1565	0.60	1565–1615	3.80
Average (±SE)		**0.6 (±0.06)**		**3.8 (±0.5)**

In summary, the dynamical pattern predicted by the demographic-structural model is apparent in data ranging across all Eurasia and from the third century BCE to the nineteenth century CE. Furthermore, the same regularity is observed in Egypt from the Hellenistic through the Ottoman periods [14]. In fact, it appears that this empirical pattern holds for all agrarian societies whose dynamics are not unduly influenced by exogenous forces, e.g., large empires (such as the Roman and Chinese ones) or island states (England and Japan).

The dynamics of religious conversion

The last example concerns testing dynamical theories about religious conversion (Turchin [31], ch. 6). Three more-or-less explicit models for religious conversion and ethnic assimilation have been proposed in the literature: the noninteractive, the autocatalytic, and the threshold models. The justification for each of the model does not concern us here (the details are in Turchin [31], section 6:2:1); what is important is that each model predicts a qualitatively different trajectory (the proportion converted/assimilated as a function of time). This means that we can determine which theory better reflects the reality if we can find data on the temporal course of conversion.

Empirical data on conversion to Islam in Iran and Spain, all strongly supported the autocatalytic model and were nothing like trajectories predicted by the two alternatives (figure 3a,b). What do we conclude from this result? All models are by definition wrong, because they oversimplify the complex reality, but the autocatalytic model is less wrong than the alternatives. It appears that the assumptions of the conversion process built into the autocatalytic model capture some important aspect of the reality.



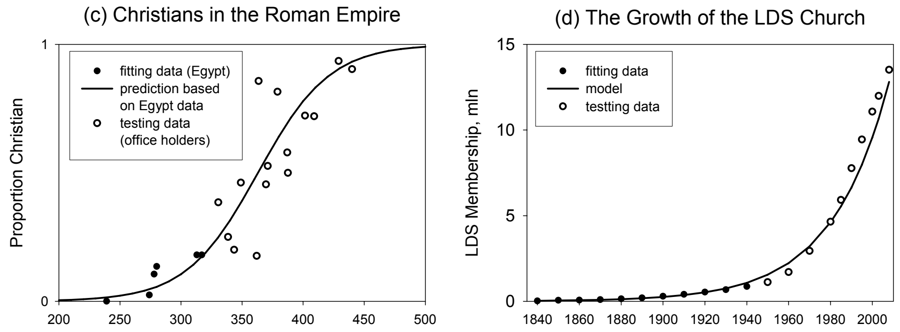


Figure 3. The dynamics of religious conversion. Trajectories of conversion to Islam in (a) Iran and (b) Spain. The curve is the fitted autocatalytic model (the logistic equation). Out-of-sample predictions: (c) Christians in the Roman Empire and (d) the growth of the Mormon (Latter-Day Saints) Church.

Note that the three conversion models that I considered were not flexible statistical models, such as splines or neural nets. They were based on specific assumptions about mechanisms underlying conversion, and predicted qualitatively different shapes of trajectories. Thus, the comparison between theoretically predicted shapes and the empirically observed ones was definitely a step forward, because it roundly rejected two of the models in favor of one. Nevertheless, each model had tunable parameters, and it would strengthen the result if one model were capable of successfully predicting out-of-sample data ("in-sample" refers to data used in model fitting, "out-of-sample" data are those that were not used in fitting but were reserved for testing the model; or perhaps were collected after the model was fitted).

There was an element of out-of-sample prediction in the test a third data set, involving conversion to Christianity (Turchin [31], section 6.3.2). This case study was based on data in the book by Rodney Stark [24] on the rise of Christianity (see also Hopkins [9], Stark [25]). Stark used a variant of the autocatalytic model to predict how the number of Christians in the Roman Empire grew from the first century on. He estimated (guessed, really) that there were roughly a thousand converts in 40 CE and that their numbers grew at the rate of 40% per decade. Several years after he made these estimates, a colleague attracted his attention to the reconstruction by Roger Bagnall of the growth of Christianity in Egypt, based on data in Egyptian papyri. Since Stark was unaware of Bagnall's data at the time when he constructed his prediction, we have here a true test with out-of-sample data.

This story has a sequel. Two years after I wrote the chapter on conversion in *Historical Dynamics* [31], I happened on a reference to a German dissertation that gave a list of Pagan and Christian office-holders between 324 and 455 [40]. I immediately realized that these data enable us to make another test of the autocatalytic model [34]. The results are shown in Figure 3b. We see that the curve fitted to the Bagnall data (showing the proportions converted before 300 CE, filled circles) does a very good job predicting the course of Christianization in the von Haehling data (after 330 CE, hollow circles). The coefficient of prediction (the proportion of variance of out-of-sample data predicted by the model) is a healthy 0.57.

A similar, although less dramatic, exercise can be performed with the data on the growth of the Mormon (Latter-Day Saints) Church [26]. The model fitted to the data up to the outbreak of World War II does a very good job predicting post-War trajectory (figure 3d).

Taken together, the results in Figure 3 tell a remarkable story. They suggest that once world religions got going, they generated a kind of momentum that allowed them to expand at approximately constant (per capita) rate. Dramatic events – world wars, imperial collapses, and nomadic invasions – did not derail these massive macrohistorical processes, at least in these particular cases (of course, certain kinds of events, such as the Christian Reconquista in Spain, are capable of reversing the tide of religious conversion).

Conclusion

The empirical studies surveyed above are each based on a powerful macrohistorical regularity cross-cutting across world regions and historical periods. Although Kosovo and Vietnam (to use Robert Darnton's example) differ in many ways, at some deeper level their economic and political dynamics may be driven by similar mechanisms. Certainly, Ancient Rome, Imperial China, Capetian France, and Romanov Russia are as different from each other as Kosovo from Vietnam. Yet these states all arose on metaethnic frontiers and experienced a sequence of secular cycles [33].

History is not "just one damn thing after another." Strong empirical patterns arise because the dynamics of historical societies reflect the action of general social mechanisms. There are laws of history (in the broad sense of the word). Furthermore, successful case studies of scientific prediction, reviewed in this article, show that we are well on the way to identifying some of these laws.

As I noted in the Introduction, attempts to transform history into an analytical, mathematized science have been made before, but were largely unsuccessful. One of the most ambitious efforts is that of Nicholas Rashevsky [21]; a book that, unfortunately, has been largely ignored. How is the situation different today?

Two recent developments, one theoretical and another empirical, have dramatically changed the scientific landscape.

First, the advances in nonlinear dynamics and complexity science have revolutionized how we do theory in science, even (especially) in such difficult fields as history. Our theoretical approaches to complex systems are no longer limited to verbal theories. Dynamical models, such as systems of differential equations, allow us to handle precisely and quantitatively such issues as the importance of contingency and dependence on initial conditions. Such hoary issues as "chance versus necessity" can now be addressed quantitatively by models combining deterministic and stochastic terms (Turchin [31], pp.6,14). Agent-based computer models (Epstein and Axtell 1996) is another key tool for investigating the effects of stochasticity and the influence of individuals on the historical process. This approach is also custom-made for investigating how macro-level patterns arise from micro-level interactions.

Second, the recent years saw a qualitative increase in the amount of data available for testing theories about historical dynamics. The key development has been the spread of computer use among the historians and the rise of the Web. As a result, more and more datasets are now easily accessible through the Internet. To illustrate the potential consequences of this shift, consider that invaluable tool of a macrohistorian, the historical atlas. Traditional book atlases are inherently limited. A typical problem is that either the region or the period, in which one is interested, is not in the list of maps collected in the atlas. Furthermore, traditional atlases are ill-equipped to portray dynamical change. What we need is a computer-based dynamical atlas that allows one to zoom in on arbitrary geographic regions and play movies to gain an understanding of temporal changes occurring there. Such a perfect atlas does not exist yet, but I know of several initiatives to create one. It is a matter of years, not decades, before we have one.

I argue that we already have the necessary analytical tools for modeling historical processes and statistically analyzing data. Naturally we need more data, but it is clear how to increase our "empirical capital" – all it takes is more hard work. The greatest challenge that I see is a conceptual one: how do we construct meaningful theory? How do we define and theorize the key variables on which our dynamical models will be based? Some variables are conceptually easy. To study the demographic and economic aspects of historical societies all we need to do is to bring in the concepts already worked out by demographers and economists. That is clearly why demographic history and cliometrics [6, 7] were the first fields of history where the scientific method was systematically applied.

Other variables are much more difficult to wrap one's mind around. As an example, take social cohesion, or the capacity of a group for collective action, for which, I have proposed [31, 33], we could use Ibn Khaldun's term asabiya. It is clear that the Romans of the third century BCE, during the Punic Wars, possessed much greater asabiya than the Italians of the fifth century CE, when the Roman Empire in the West was in the process of disintegration. But how do we define and measure this change? (One thing is certain, if we can figure out how to measure asabiya, its units will be called khalduns.) It seems to be a nebulous, hard-to-pin-down quality. Yet recently there has been some progress in measuring it. I am thinking of the concept of social capital as proposed and used by such political scientists as Robert Putnam (and not to be confused with the social capital of Bourdieu [3], Putnam et al., [19], Putnam [20]). As I have argued earlier, social capital is none other than asabiya for modern societies (Turchin [31], p.43). Putnam and coworkers proposed a variety of approaches to measuring relative amounts of social capital among different Italian provinces [19], as well as changes over time in the United States [20]. Thus, although at first a concept may appear nebulous, hard work involving theory development and empirical testing may, in the end, lead to precise definitions and ways to obtain quantitative measures. It is important to remember that physics, which appears to us now as a hard science, or biology, had to travel the same route. Such difficult concepts as, for example, entropy, were not obvious right away, and arose as a result of lengthy collective labor by many scientists.

In this essay I have looked back at the history of natural sciences and argued that, although at present the obstacles to developing a scientific history appear to be formidable, we forget that natural sciences overcame similar challenges during their infancy periods. I am convinced that historical scientists will also solve the problems of how to conceptualize and measure key theoretical variables in cliodynamics, how to build meaningful theory and then test it empirically. It will take time and a lot of work. But what is encouraging is that, as the empirical "success stories" show, we are already well on the way toward a science of analytical, predictive history.

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