The Coevolution of Everything, Everywhere, All at Once: Institutions, Culture, and the Great Enrichment

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Abstract

Although institutions are humanly devised, they are also emergent phenomena that cannot be closely controlled or predicted. In addition, institutions emerge in coupled coevolutionary dynamic with culture, as well as other evolving systems such as technology, geography and language. The coevolution of culture and institutions, which is the focus of this paper, means that changes in culture alter the fitness of the current designs of institutions, which leads to changes in institutions, which feeds back altering the fitness of current culture, in unpredictable coevolutionary dynamics. I model this process using coupled fitness landscapes and Boolean hypercubes to show how coevolutionary processes cannot be foretold or finetuned, as they exhibit sensitivity to initial conditions, path dependence, non-optimality, multiple-equilibria, instability, uncertainty, mismatch, and non-ergodicity. The paper also explores how human ultrasociality and the collective brain play a role in this coevolutionary process. As an example, the paper explores the Great Enrichment – the rise of modern economic growth – through the coevolution of institutions – such as the Western Church's Family and Marriage Program, the Republic of Letters, impersonal markets – and culture – such as, individualism, belief in useful knowledge, impersonal prosociality. This analysis highlights the contingent and emergent nature of long-term economic history.

Keywords: Coevolution; Institutions; Culture; economic growth; complexity.

I. Introduction

Evolution is one of the most powerful ideas for understanding how things work, how they change and how the diversity we see all around us is created. Darwin's dangerous idea, as labeled by Daniel Dennet (1996: 63) is "like a universal acid that eats through just about every other explanation for life, mind, and culture." It is, superficially, also an amazingly simple and intuitive idea: because things – organisms, ideas, beliefs, artefacts, technologies, songs, jokes, and many others – are reproduced with variation, new instantiations that are "better" than others (more fit to the environment) will be reproduced at greater rates and will come to dominate in the population. This simple algorithm of variation-selection-replication is the driving force behind the existence and diversity of life and of everything else we know. This point has been forcefully argued by Matt Ridley in his 2015 book *The Evolution of Everything*, where each of 17 chapters is dedicated to describing the evolution of something different: the universe, morality, life, genes, culture, the economy, technology, the mind, education, population, leadership, government, religion, money, the internet, and the future.

If evolution is, as Ridley argues "the best way of understanding how the human world changes, as well as the natural world", why is it not more dominant in social sciences? While all social sciences have fields, schools of thought and journals that feature evolutionary principles, such as evolutionary economics or evolutionary theories of law, these are rarely dominant and are often quite marginal within the disciplines and professions. Especially in economics it is puzzling that evolution is not more widely invoked, after all, according to Ridley the economy, technology, education, government, and money – all directly relevant to economic processes and outcomes – change by the evolutionary algorithm.

The reason why evolution has never really caught on more broadly in economics may be related to the general mindset and attitude that pervades the discipline. The role of the economist is seen as understanding, predicting, and controlling markets and economic processes. Students of economics are lured by the promise of a toolkit of concepts, models and prescriptions that allow them to diagnose market failures and fix the world through policy recommendations and implementation. It is a fundamentally reductionist and linear approach which seeks to understand complex phenomena by breaking things down to their micro elements, that are more easily apprehended, and then piecing those separate parts back together to understand the macro whole. Given such values and expectations, it is no wonder that evolutionary approaches are eschewed. After all, the evolutionary lens offers a perspective that has quite the opposite feel and disposition. Evolution is spontaneous, emergent, undirected, surprising, inevitable, relentless, often unexplainable, and not the result of human design. The current obsession in economics with causal inference, useful as it may be for many types of inquiry, sits at odds with evolutionary processes which are simultaneous, dynamic, ever-changing, non-ergodic and sensitive to initial conditions, making them not amiable to simple x-causes-y type of statements.

With such different values and outlook for how science should be done it is not surprising that evolution has remained a fringe endeavor in many social sciences. But it is worse than this. While plain evolution may be unpalatable to those with reductionist and linear scientific expectations, postulating that everything evolves is actually a simplification. Things are even messier and less tractable than implied in the view that everything evolves. Instead, everything coevolves. And coevolution means systems are orders of magnitude harder to apprehend, predict and control.

Coevolution recognizes that nothing evolves alone and in a fixed environment. Instead, when one species evolves a new trait, it can affect the evolution of another species. This happens because the environment of each species is often composed in part of other evolving species. This makes the selecting environment endogenous and reactive. In a predator and prey relation, for example, if the prey evolves a better camouflaging coat, the predator's current design is no longer as fit for its environment – which includes the prey - as it previously was. The evolution of the prey thus puts selective pressure on the predator to evolve counter traits given this new environment, perhaps improved eyesight or sense of smell. And a given species does not have a single coevolutionary relation but several simultaneous couplings of different types (parasitic, mutualistic, competition for resources, etc.), not to mention coevolution with the physical environment, such as when beavers disrupt rivers and shape their surroundings, which in turn affects the fitness of their own current design (Odling-Smee et al. 2013). Thus, the coevolution of everything, everywhere, all at once.

That species not only evolve, but actually coevolve in an entangled web of complex interactions was already understood by Darwin, who hypothesized that this is what explained the existence of flowers with long floral tubes and moths with long tongues. The flowers offer nectar at the bottom of the tubes to force the moths to rub against the flowers' reproductive parts at the top. Moths with longer tongues can reach all the nectar but then provide less pollination services, so the flowers are under coevolutionary pressure to evolve longer tubes. At the same time moths adapt by evolving longer tongues, as those that access more nectar will reproduce at greater rates than moths with shorter tongues (Johnson and Anderson, 2010).

At first blush the account of the mutualistic coevolution of moths and flowers, as well as many other examples of evolution and coevolution, seems satisfying from a reductionist, linear and causal-centric perspective. Everything fits, makes sense, and is accounted for, and the mechanisms through which one thing causes the other are clear. However, such just-so storytelling was disparaged by Richard Lewontin and Stephen Jay Gould (1979) who coined the term by allusion to Rudyard Kipling's *Just So Stories for Little Children* (1902), that provides fantastical explanation for why animals are the way they are (e.g., how the leopard got its spots) (Hubalek, 2020). Their point is that when it comes to evolution and coevolution many different stories or explanations can be concocted, but in general there is no way to verify if they are true, and it is not the proper work of a scientist to make up such stories. This inconvenient perspective for a reductionist scientist cannot be overcome by brute force, employing more data, more powerful computers, better models, more rigorous theories, and smarter experts. The case of the moth and flowers, for example, is a great abstraction that makes it seem as if the coevolutionary race involves the single dimension of tongue and tube length. In reality, such coevolving interactions can explore multiple other dimensions such as thorns, chemicals, camouflage, mimicry, and strategies that even experts in the field would not have dreamt up. As per Orgel's second rule, "evolution is cleverer than you are" (Dennet, 1996: 74) and inevitably begets surprises and frustrates predictions.

In this chapter the focus is on the coevolution of culture and institutions and how their interaction with each other and with other coupled systems such as technology, geography, and language, affect long-term economic growth. Much of the debate in this area has sought to uncover a single silver bullet 'fundamental cause' of long-term growth. Empirically it has focused on finding historical natural experiments that allow for the causal identification of these separate treatment effects. Bisin and Verdier, (2017: 3) express skepticism about attempts to do this with slow-moving non-stationary processes such as long-run history and argue that with coevolution, "the origin, and hence the causation, question loses most of its interest … the focus is moved from cause to the process as determined by the interaction." Nathan Nunn similarly notes that even studies that manage to deal properly with all the obstacles for identifying causation end up explaining a surprisingly small part of the variation across countries, leaving often more than 97% unexplained.[1] Those unaccounted for 97% include all the apparent messiness of the multiple coevolving causal factors.

The focus on such a narrow slice of the whole phenomena of interest, sacrificing a more complete, albeit messy, understanding for the sake of a deterministic answer, is akin to the emphasis in economics on partial instead of general equilibrium analysis. In partial equilibrium approaches a single market is analyzed taking all other markets, prices, and controls as fixed. It gives clear predictions but in unrealistic and often not so useful contexts. General equilibrium models, on the other hand, try to explain all markets at the same time, thus providing a more realistic analysis. But doing so turns out to be so intractable and so implausibly data reliant that the only way to get results is to impose a whole other set of assumptions that also make the exercise often not very useful for practical purposes.

It is interesting that in his book Matt Ridley does not once use the word 'coevolution'. This is not because he does not know that everything not only evolves but also coevolves. It was probably a choice akin to that of economists to focus on partial instead of general equilibrium. Faced with the hard sell of the idea that evolution is the most powerful concept in the universe, the objective of his book, it may have been preferable to abstract from the manifold additional complications that would have to be addressed if coevolution were included, as this might simply put off many of the more reluctant readers. In this chapter, in a

[1] Nunn, N. (2023) How the World Became Rich – Book Panel. F.A. Hayek Program Podcast, Mercatus Center. https://www.mercatus.org/hayekprogram/hayek-program-podcast/how-world-became-rich-book-panel

Handbook of Institutions and Complexity, I can assume readers are more open to complex, emergent phenomena, and my objective is to describe ways to understand how and why everything coevolves and its implications. I do this by using fitness landscapes and Boolean hypercubes. While the use of these approaches for understanding evolution is well known, their extension for coevolution is less familiar. I then show how these theoretical concepts can be used to understand the most remarkable phase transition in human history, the Great Enrichment through which a subset of countries broke free of perennial Malthusian pressures to achieve, quite suddenly in historical time, unprecedented levels of economic growth, increased prosperity, and technological progress. Rather than the usual silver bullet approach I emphasize the coevolution of institutions and culture, and everything else, such as technology, beliefs, language, and geography.

II. Institutions, Culture and Coevolution in Economics

If economists from before the mid-1990s were to examine the topics treated in mainstream economic journals today, they might be surprised at the large number of papers that explicitly focus on institutions and culture or that use these concepts prominently in their analyses. Prior to this time the avowed objective was precisely to explain the world through purely economic variables, without resorting to anything that implied endogenous preferences or excess of context or detail, as these were seen as difficult to measure and to model thus allowing for ad hoc explanations that, by explaining everything, explained nothing (Stigler and Becker, 1977; Friedman, 1953).

Institutions were the first to break into the mainstream. Although much of the current body of theory on new institutional economics was already well developed by 1990, by authors such as Douglass North, Ronald Coase, Elinor Ostrom and Oliver Williamson, it was only in the 2000s that the mainstream of the profession overcame its reluctance and embraced institutions as a central and indispensable concept, in large part due to the popularization of the approach in work by Acemoglu and Robinson. We are all institutional economists now.[2]

The embrace of culture came later. If institutions are the “humanly devised constraints that structure political, economic and social interactions”, as famously defined by North (1991), how is it that humans go about devising institutions? Necessarily the process must involve a conceptualization of how the world works, that is, a set of beliefs, attitudes, and

[2] The fact that Ronald Coase and Douglass North had been given Nobel Prizes in Economics in 1991 and 1993, respectively, does not mean that they were by definition in the mainstream. The Nobel Prize is often given for originality and for the value of ideas, which do not necessarily correlate with fieldwide impact or consensus.

preferences (or culture) that guide the choice of institutions for the purpose of achieving intended goals. But it was probably not the efforts to conceptualize how culture impacted economic performance directly or through institutions, as done by North (2005) or Grief (1989), that was crucial in this embrace. Rather, culture in economics only really took off once work started to appear showing that culture could be measured and used econometrically to test how the distant past impinges on current economic performance. Whether culture measured historically (e.g., individualism or gender roles) is used to explain current economic outcomes (e.g., GDP per capita or innovation) or current beliefs and attitudes (e.g., belief in redistribution, or antisemitism), history suddenly became popular in economics and culture played a key role as either dependent variable, treatment, identification strategy or confounder (Voth, 2021; Nunn, 2021).

The recent growth in interest and acceptance of culture in the economics literature can be shown by the number of surveys that cover culture and economics (Fernández, 2008, 2011; Lowes, 2022; Nunn, 2022; Beugelsdijk and Maseland, 2010; among others). Even in the more focused theme of culture and institutions there are enough surveys to enable a survey of surveys (Alesina and Giuliano, 2015; Bisin et al. 2021; Bowles et al., Galor, 2022; 2021; Mueller, 2018.). Another measure of the interest is the number of papers with 'culture' and 'institutions' in the title (Acemoglu and Robinson, 2021; Belloc and Bowles, 2013; Bisin and Verdier, 2017, 2021; Bisin, Seror and Verdier, 2019; Kafka et al. 2020; Lowes, Nunn, Robinson, and Weigel. 2017; Mueller and Leite, 2020; Persson and Tabellini, 2021). And of course, the number of papers that consider both culture and institutions, though not in the title, is much larger. The survey by Alesina and Giuliano (2015) on "Culture and Institutions" covers 200 papers. It is structured with a section covering research that shows how culture can affect formal institutions, followed by another section on research on how formal institutions can affect culture. But as these authors admit, the most promising approach, which they review in a third section, seeks to study "the interaction between culture and institutions recognizing and embracing a two-way effect to explain economic development and other types of economic outcomes, rather than stressing causality in one direction or the other" (pg. 928).

It is common to see the word 'evolution' used loosely to refer to any kind of change overtime, and 'coevolution' to describe systems that are in any vague way interrelated. There is, however, a well-established literature within economics that models the coevolution of culture and institutions mathematically yet explicitly taking into consideration the Darwinian nature of that coevolution, that is, that cultural traits and institutions with higher relative fitness tend to spread, and that the transmission of each, institutions and culture, depends on the form of the other (Bisin and Verdier, 2001, 2005, 2017, 2021; Grief, 1994, 2006; Persson and Tabellini, 2021; Tabellini, 2008). These are jointly dynamic models where there is generally no static equilibrium but where the interest is in the characteristics of process through which culture and institutions interact. These characteristics usually fall in two categories, where institutions and culture are either substitutes or complements on the effect they have on outcomes such as economic development, accumulation, innovation, corruption, etc. When they are substitutes, cultural traits conducive to cooperation or saving, for example, are easier to sustain if institutions are weak: the introduction of stronger formal institutions would obviate or lessen the reliance on cultural inducements. When they are complements, cultural traits such as civic capital, for example, enhance the functioning of formal institutions. Though it is common to try to recognize substitute or complementary steady states or dynamic equilibria in history, these are best not thought of as fixed or ineluctable. Over historical time these trajectories are subject to incremental change and to major shocks and critical junctures, due to things like wars, epidemics, colonization, technological change, climatic change, and others, which can change the nature of the coevolution, often in radical ways.

Acemoglu and Robinson (2021) also model the coevolution of culture and institutions mathematically but take a more fluid view of culture. Whereas most of the approaches in economics have adopted the view pioneered by Talcott Parsons (1951) that culture is stable, coherent and sticky, they treat culture as less coherent and stable, and more adaptable allowing for choice and variation even after the stage of childhood transmission (Di Maggio, 1997; Geertz, 1973). In Parson's approach, culture is more fundamental and institutions are subordinate, but for Acemoglu and Robinson (2021: 3) "culture and institutions are more like siblings, each affecting the other, and sometimes one emerges as primary and sometimes the other." They identify a culture set composed of several cultural attributes that can be wired and rewired depending on circumstances to form different cultural configurations. While the culture set is more stable and persistent, cultural configurations are more ephemeral and adaptable, changing with institutions.

In this chapter I provide a complementary approach to modelling coevolution, which also allows cultural and institutional attributes to be turned on/off and to be rewired. It is based on fitness landscapes initially developed by Sewall Wright (1932) and widely adopted in biology and evolutionary theory. Fitness landscapes were described in chapter 2 of this Handbook as one of the five most appealing concepts in complexity theory. They are a well-known tool which provides an intuitive and visual way to represent and analyze the task of producing innovation or solving problems, that is, the problem of survival and reproduction, be it of biological organisms or of entities such as technologies, routines, languages, culture or institutions. Fitness landscapes can be used more loosely and metaphorically, but they can also be formalized, such as in Kaufman's (1993) NK model. Although fitness landscapes are much used in the context of evolutionary change, their use to model and analyze coevolution is less well-known as it is more difficult to graphically represent the dynamic nature of coevolutionary change. In section 4 I describe how coupled adaptive fitness landscapes can be used to model the coevolution of two or more systems such as culture and institutions. This exercise will show that coevolutionary dynamics are emergent, surprising and unpredictable, and though not amenable to equilibrium analysis, is still useful to understand the characteristics of these systems' interaction. Before this, however, I provide in the next section a broad overview of the stylized facts and timing of how culture and institutions have coevolved since the rise of humanity.

III. The scale of the coevolution of culture and institutions

Everything coevolves, but scale matters. The coevolution of institutions and technologies can operate at the scale of a few years, such as when stronger intellectual property rights induce new technologies – e.g., the internet –, and these in turn foster new forms of property rights – e.g., blockchain. Other forms of coevolution, such as gene-culture coevolution, operates over centuries or millennia – e.g., bigger brains foster the expansion in the pool of cultural information, and more cultural information puts pressure for ever larger brains (Henrich, 2015). Yet other forms of coevolution may operate at even greater scales, such as the coevolution of geography and systems such as technologies and genetically evolved psychology. Furthermore, these interactions are not just pairwise, but happen all at once across scales. For example, geographies suited for plough agriculture fostered the evolution of this technology, which, due to the requirement of upper body strength led to historical gender division of labor, inducing persistent gender norms, institutions, and even language evolution through gender-based grammatical distinctions, e.g., in Romance languages, all of which feeds back on geography and climate as technologies, institutions, attitudes, and others induce colonization, climate change, biodiversity loss, among others (Alesina, Giuliano and Nunn, 2013; Boserup, 1970; Galor, 2022). In the simplified manner stated here this example comes close to the just-so critique alluded to above. The whole point of this chapter is that the web of coevolutionary processes is so complex, entangled and at different scales that it is not useful to treat it as a set of neat, apprehensible, and straightforward relations. Of course, depending on which specific processes we are interested in, some of the processes that operate at different scales can be taken as fixed.

Figure 1 provides a timeline that gives an overview of some events and changes in the coevolution of institutions and culture since the origins of homo sapiens. Each element of the figure indicates an important source recognized in the literature. The shape of the graph shows that since the arrival of homo sapiens, approximately 300 thousand years ago, the average level of income remained at subsistence level, with the exception of the past 250 years when a small group of countries managed to achieve exponential economic growth. The population figures, shown at the top of the graph, together with the GDP per capita, show the logic of the Malthusian Trap, which prevailed through most of this history and even today in many countries. Occasional and localized increases in living standards, due to luck, technological change, better organization, or other factors, quickly induced population growth. But because population systematically increased faster than productivity, improved living standards could not be sustained, and the new equilibrium would be a greater population but at the same Malthusian income threshold.

Much of the effort in economic history to understand and explain the Great Enrichment and the Great Divergence, shown in the right side of the graph, has focused on how institutions as well culture have determined these stylized facts and outcomes (see references in the figure notes). Events such as the Neolithic Revolution (Bowles and Choi, 2019), Glorious Revolution (North and Weingast, 1989); colonization (Engerman and Sokoloff, 2002; Acemoglu, Johnson and Robinson, 2001), and the Industrial Revolution (Smith, 1950; McCloskey, 2016; Mokyr, 2016; and others) have been explored as points where either institutions or culture or both where somehow locally modified in ways that contributed towards initiating the transition to greater innovation, productivity and prosperity.

In addition, the timeline reaches back to the beginning of our species, as our biology, psychology, and genetic diversity have evolved over these 300 millennia (and actually much earlier through our common ancestors) in ways that are important for understanding these characteristics in present times. This early coevolutionary period stretched across more than 10,000 generations, which was time enough for the evolution of our current biological package as well as an evolved psychological and cultural package often referred to as collectivism, composed of kin-based morality and altruism, distrust of strangers, and strong in-group/out-group distinctions. In the mere 400 generations since the Neolithic Revolution our biological evolution has been limited, but both institutional and cultural evolution have changed greatly. In particular, we are interested in the rise of a different cultural and psychological package, known as individualism, that displays impersonal trust, generalized morality, relational mobility, less conformity, and other attitudes and values that prioritize the individual (or nuclear family) over the extended family, clan or tribe (Henrich, 2020). This new cultural package gradually induced an expanding set of new institutions, such as markets, constitutions, laws, guilds, associations, and rules of marriage, among many others. These in turn have fed back, constraining, honing, or changing cultural elements. That is, the coevolution of culture and institutions entered a phase transition in certain societies that generated the innovation, science, markets, and social/political organization, that are behind the exponential rise in prosperity shown in the right-hand side of Figure 1. In section 5 I provide a detailed account of the rise of individualism in Europe and its impact on prosperity as, perhaps, the most striking instance of culture-institution coevolution in human history.

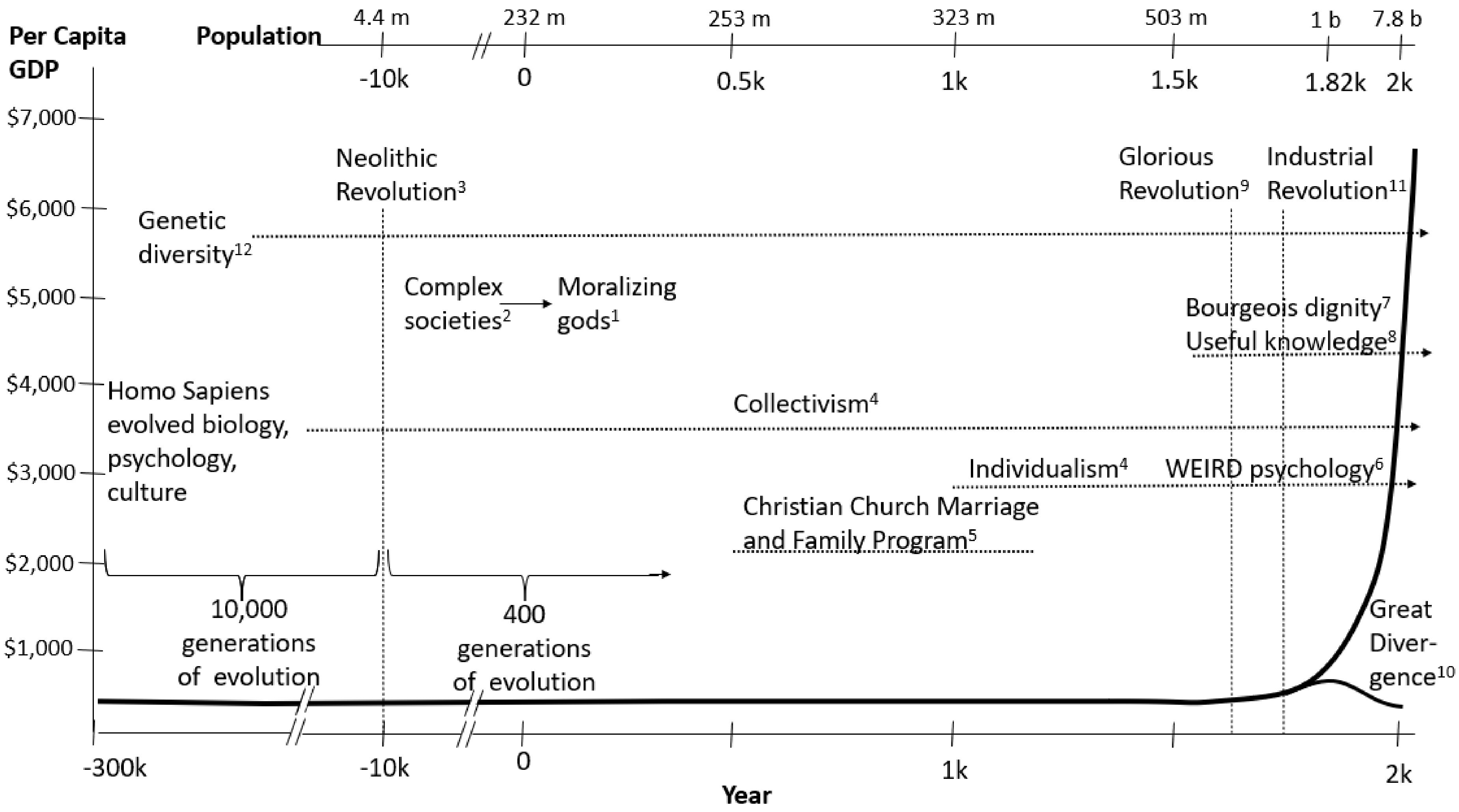

Figure 1: Timeline and scale of the cultural evolution

Notes: 1 - Turchin et al. (2018); 2 - Whitehouse et al. (2019); 3 - Bowles & Choi (2019); 4 - Greif (2006); 5 - Henrich (2020); 6 - Henrich et al. (2010); 7 - McCloskey (2016); 8 - Mokyr (2016); 9 - North & Weingast (1989); 10 - Pomeranz (2000); 11 - Smith (1950); 12 – Ashraf and Galor (2013). Population data from *Our World in* Data https://ourworldindata.org/search?q=population. The general shape of the graph and GDP estimates are based on Delong (2003).

It is tempting to interpret the trajectory in figure 1 as essentially inevitable. It seems reasonable to assume that one way or another humanity would innovate, organize, and discover ways to improve the quality of life. It may also seem evident that however this would have come to be, more or less the same stages would have to be followed and that the timing of the transition to agriculture and then the exponential rise in wealth would be approximately what was actually observed. But these impressions are highly influenced by our propensity to, after the fact, view whatever happened as obvious and inevitable. Because what happened, happened, it is hard to conceive that it could have transpired differently (Watts, 2011).

But if one considers the trajectory as the emergent outcome of a complex adaptive system in which everything coevolves, a very different interpretation is possible. Consider history as a specific 'run' – in the sense of an algorithm that can be run in a system several times - given initial conditions and boundary conditions. Systems of interacting agents can display very different behaviors and outcomes in different 'runs', even if the basic parameters are the same. In some runs emergent phenomena and spontaneous order may quickly materialize, in others much later or not at all. With history we only have one run, and despite our inbuilt propensity to take it as ineluctable, we can never know if it was a representative run or fluke.

Bowles and Choi (2013) built a model of the coevolution of farming and private property during the Holocene that illustrates this point. The standard accounts of the transition from hunter-gathers to agriculture are based on the appearance of a new technology (agriculture), population pressure or other exogenous changes. These authors challenge these explanations by noting the chicken and egg puzzle where farming required private property to emerge while private property could not emerge without farming, as it was not cost effective to demarcate and enforce property rights over wild plants and species. Their explanation postulates a coevolutionary dynamic in which, once climate variability reduced towards the end of the Pleistocene, in areas rich in hunting and gathering resources, sedentism could emerge allowing for property rights over some resources. These could then facilitate the rise in farming, which would then feedback, strengthening the use of property rights. For this to happen the joint emergence of new technology and property rights would have to be achieved reaching a critical mass to allow for the phase transition, and this could then be emulated by other neighboring groups. They note that enduring transitions were rare, diverse, protracted and frequently reversed. The fact that humanity did eventually make this transition in most places, masks the possibly exceptional nature of the process. In the agent-based model they built to simulate the coevolutionary emergence of agriculture, the transition took place, with timing that reasonably reproduced the archeological record, in only 31 of the 1,000 simulated meta-populations. The authors note that "the key event here is thus not the 'invention' of farming but the coincidence of sufficiently many individuals adopting both the novel property rights and the new technology so as to overcome the critical mass problem" (Bowles and Choi, 2013: 8834).

Another explicitly complex system interpretation of the Great Enrichment is Joel Mokyr's suggestion that this exceptional transformation may not have been an ineluctable consequence of the march of human progress but instead a Black Swan or a 'fluky one in a history event'.[3] He stresses that despite the propensity for history to seems obvious once it has unfolded, not everything that could have happen, happened, and what happened could very well not have happened. He identifies in human history four sources of negative feedback that together assured long run stability by dampening any event or change that happened to generate increases in wealth and prosperity: (i) the Malthusian trap dynamic discussed above, (ii) prevalence of predators, invaders and local rent-seekers; (iii) exogenous shocks such as epidemics and climate change, (iv) the 'curse of concavity', that is diminishing returns to things that raised income, such as gains to trade or capital accumulation. A complex system subject to such rules or parameters may generate innovation and wealth, but any success automatically elicits countervailing forces that ensure that prosperity is short-lived pushing the system back to its Malthusian threshold stability.

But in the early 18th century, according to Mokyr, these four dampening factors were challenged by emergent countervailing forces. In particular, the Enlightenment contributed towards making intra-European predatory wars unfashionable, to mitigate the influence of religions, leading to reduced fertility, and above all led to the rise of a belief in useful knowledge as the engine of economic progress. Where these positive feedbacks happened to triumph over the reactionary forces of negative feedback the curse of concavity was lifted and led to the explosive increase in prosperity. Once this process of growth had taken roots it became very resilient, resisting even wars, depressions and other traumatic events of the 19th and 20th century. The process is based on knowledge, and knowledge has the property that once it has been created it does not go away but multiplies and creates new knowledge.

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[3] Mokyr espoused this view in the Hayek Program podcast in a review of the book *How the World Became Rich* by Mark Koyama and Jared Rubin https://www.mercatus.org/hayekprogram/hayek-program-podcast/how-world-became-rich-book-panel

What is remarkable in Mokyr's proposition of the Great Enlightenment as a phase transition in a complex dynamic system is how it goes against the prevailing view in much of economics and in economic history that large events must have large causes, what McCloskey (1991) has called the Dogma of Large-Large. Because history is often iterative, non-linear, and coevolutionary, small events, possibly unremarkable when they happened and thus not even included or stressed in historical accounts, may have been instrumental in the great changes that eventually transpired, as in the childhood rhyme that McCloskey (1991: 25) revives: For want of a nail the shoe was lost. / For want of the shoe the horse was lost. / For want of the horse the rider was lost. / For want of the rider the battle was lost. / For want of the battle the kingdom was lost. / And all for the want of a horseshoe nail.

IV. Coevolution as dancing landscapes

The fact that evolving and coevolving systems are unpredictable and hard to command or control does not mean that they cannot be modeled. It just means that the models cannot be used to pinpoint what will happen or to favor preferred outcomes. They can be used, however, to better understand the nature of the processes and the broad characteristics of the types of outcomes that may emerge. These limitations are not shortcomings of the models but rather misplaced expectation of what can truly be known in a complex world.

In essence, fitness landscapes model the problem of search. They are useful for modeling evolution and coevolution because these are essentially processes for searching for solutions to problems. In biological evolution the problem is survival of the genes. In cultural forms of evolution, the problem is the survival (passing on to others) of beliefs, attitudes, values, etc. Sometimes it is more useful to think of landscapes as representing search for innovation, given that innovations are solutions to problems.

Fitness landscapes look like topological maps. The base of the map arrays all the possible solutions or designs related to a specific problem, such as how to design an animal to live in a given environment, say a swamp, or how to design a better steam engine. The landscape is finite but too large to fully apprehend or explore more than a tiny fraction. Each design is placed next to designs that are identical in all but a few ways, so that contiguous regions in the landscape are populated by similar designs. The fitness of each design is plotted vertically above each point. Fitness is not a measure of quality or efficiency, but rather a measure of how likely that design will be replicated or transmitted to future generations. Because similar designs neighbor each other, most areas in a landscape are composed of smooth hills: small changes in design typically have small impact on fitness. In contrast, the landscape for the design of a key to open a given lock would have zero fitness everywhere, except for one design that would have a spike indicating maximal fitness.

The search process occurs as variation is introduced to current designs. In biology this takes place through the recombination and mutation involved in sexual reproduction. In cultural evolution it happens as information is transmitted, for example from parents to children or horizontally across peers. Because transmission is noisy and prone to errors, this gives rise to new beliefs, attitudes, values, technologies, etc. This process can be represented as a point on the landscape randomly producing other points in its vicinity. New designs that fall on higher points of the landscape will have higher fitness, which means that they will dominate in future iterations over the lower fitness designs. Thus, the evolutionary dynamic has designs 'climbing' the hills to reach the fittest peaks, with designs at lower elevations being abandoned or going extinct.

The shape of the landscape reflects the nature of the problem that is confronted. Some problems admit a single best solution and each neighboring solution is fit proportionally to its distance from the single best solution. In this case the problem would be represented by a single-peak (or Mount Fuji) landscape (see Figure 2). This is a simple problem that admits a single best solution that can easily be found. It is typically impossible to search the entire landscape as it is near-infinitely large, and each design can only be evaluated by trying it out. Therefore, some search strategy must be employed. For simple landscapes the fittest solution can easily be found through hill-climbing procedures that always takes the steepest path.

The rugged landscape in Figure 2 represents a complex problem that involves many interacting and interconnected parts. Following a hill-climbing strategy would take you to a peak, but there is no assurance that this is the best or even a good solution. Once you are stuck on a local peak it may be difficult to search for better solutions. In this context it matters greatly where you start, that is initial conditions crucially affect outcomes. In this context search algorithms that balance exploration with exploitation, such as evolution – variation, selection, replication – are good strategies. But note that even the best solution in the rugged landscape is inferior to the best solution in the Mount Fuji landscape, which is an artifact of the nature of the problem: complex problems, by definition, are subject to many internal constraints.

If each part of a solution is directly connected to each other part, there are so many internal constraints that the problem becomes chaotic and the landscape becomes unmanageable. All solutions are poor and wherever you are will lead to extinction. Most of the problems that interest us in society, economies and science are rugged problems, as these are the ones that can be addressed and are not obvious. According to Kauffman (1993) evolution tunes landscapes to the edge between simplicity and chaos, to achieve the delicate balance between stability and diversity that begets innovation and novelty.

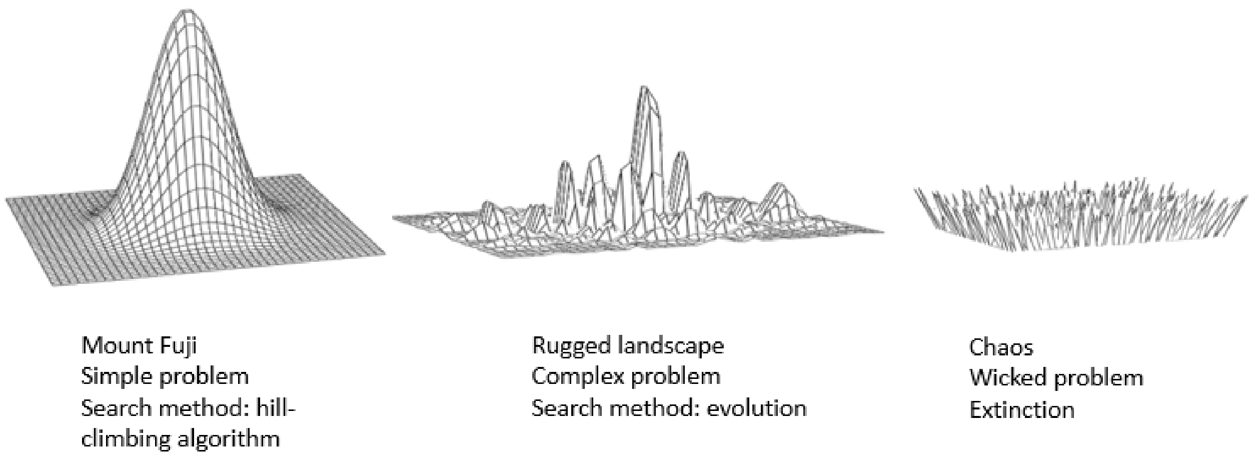


Figure 2: Mount Fuji, complex and chaotic landscapes

Landscapes provide a very visual and intuitive way to think about problems that involve creating new solutions by combining what we already know (or thing that are still unknown but already in reach) to make new ideas. This is the nature of, for example, economic development, public policies, technological progress, pharmaceuticals, musical composition, cuisine, and many others. The parts of the landscape that have already been tried are known, and the areas just beyond that frontier are the adjacent possible, where recombination is not only viable but likely. In this sense evolution can be seen as the process of expanding into the adjacent possible. Successful processes of development – a complex problem - are those that are better able at enabling this process of expansion.

Do fitness landscapes allow us to predict what novelties will emerge and how a system will evolve? Absolutely not. The major lesson from fitness landscapes is that evolving systems cannot be understood in a reductionist, deterministic and linear manner. In most cases the space of the possible is too large to be mapped out. It is not that we don't know what will happen, rather we don't even know what can happen. Even if we did, it is not possible to measure the fitness of each solution. Fitness is real, some variants are more likely to be selected and replicate than others. But we cannot infer absolute fitness or even relative fitness, except after the fact, by seeing what the environment ultimately selects. Another obstacle is the multiplicity of equilibria, which we also do not observe except for those few cases that are visited by the system. So even if we know what the best solution is and we know what the initial condition are (which we typically don't), we would not be able to infer that the system will evolve towards that solution, as it might get stuck on local peaks along the way. Evolving systems are thus non-optimizing. All of this makes these systems impossible to control, explain, and forecast beyond a narrow window of predictability, after which emergence, surprise, tipping points, cascades, punctuated change, criticality, and other consequences of the systems' non-linearities take over.

All these difficulties for modeling and understanding complex systems are compounded once we broaden our attention beyond the evolution of a single system in a fixed selecting environment to the coevolution of that system with other evolving systems that make up the environment. By relaxing the unrealistic assumption of a fixed environment, the fitness of each design is now endogenously determined so that when a given design is rendered by the system this can spark a change in the design of other coupled systems – like Darwin's flowers and moths – which in turn changes the selection pressures and thus the value of the fitness of the original design. That is, the landscape now dances through the tectonic uplifting, faulting, and folding of its peaks and valleys. With coevolution the landscape becomes a bouncy castle where the movement of one person affects the movement of the others with never-ending turbulent feedback and unexpected dynamic interactions.

How can the approach of fitness landscapes be used to model coevolution? There are two difficulties. The first is that the arraying of all possible designs on a plane where each design sits beside all of its near identical neighbors is not mathematically possible. Very quickly the plane would get overcrowded and clumped. The likeness to a topological map was a sleight of hand used to provide a more intuitive understanding. A more rigorous approach is to use hypercubes, which frees the design from the constraints of three dimensions (though I will use a simple three-dimensional case that can more easily be shown graphically). The second difficulty is that coevolution involves not just a single landscape but also the landscapes of other coevolving systems. Hypercubes provide a simple way to couple different landscapes to show how they interact.

In what follows I illustrate how coevolution can be modeled with Boolean hypercubes using the example of the coevolution of culture and institutions. To keep the graphs tractable, I assume that both culture and institutions are composed of only three dimensions each. The dimensions are components of the design or solution. That is, dimensions are information for how to render a new entity, and so must be specified somewhere, for example the information for creating a human being is specified in approximately 20,000 different genes. In my example culture is made up of three dimensions coded as either 1 or 0; D1 - collectivism vs individualism, D2 – tightness vs looseness, and D3 – conformity vs independence.[4] And institutions are made up of three dimensions or attributes that an institutional arrangement may have: I1 – inclusive vs extractive; I2 – individual vs common property rights; (3) markets vs state.[5]

Figure 3 shows the attributes of culture and institutions and provides an example of each in the form of a specific bitstring of zeros and ones. The culture coded in the example – 101 - is collectivist, loose and conformist, while the institution – 111 - is inclusive, and favors individual property and market solutions. Note also that both bitstrings have one internal constraint, shown as a link between pairs of attributes. These epistatic links make it so that flipping one dimension also flips the other. It is these internal constraints – interactions between dimensions - that make a landscape rugged, that is, more complex. If each (or too many) dimension is connected to each other, the system would be chaotic. With only 3 dimensions the space of possible cultures (or institutions) is just $2^3 = 8$. But typically, an evolving system requires a much longer bitstring to code all its details and the combinatorial nature of the space of possibilities grows quickly as the number of dimensions increases. With just 20 dimensions there are more than one million possibilities. Different links across dimensions further increase the possibilities.

[4] These are three often-used attributes of culture in the literature, usually measured through indices made with survey data: collectivism-individualism (Hofstede, 2011; Greif, 2006); tight vs loose (Gelfand et al. 2011); conformity vs independence (Schwartz, 2006).

[5] These attributes are often used to classify institutions and have also been measured through indices and proxies: extractive vs inclusive (Acemoglu and Robinson, 2012); individual vs common property (Ostrom, 1990); markets vs state (Hayek, 1944; Djankov et al. 2003; others).

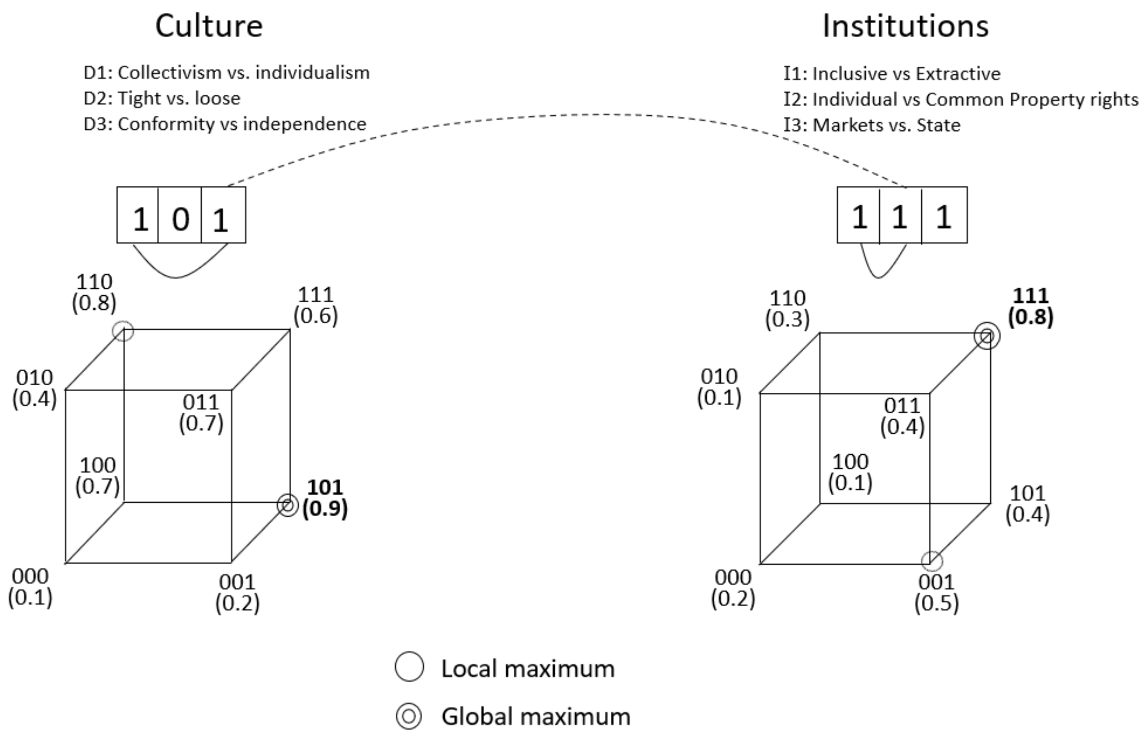


Figure 3 – Boolean hypercube fitness landscapes of culture and institutions

Figure 3 shows the space of possibilities as hypercubes. Each of the eight vertices is one rendition of culture or institutions. The figure also shows fitness values for each vertex. These are hypothetical as there is no way to measure fitness (as one cannot measure utility in economics). The evolutionary dynamic on the hypercube is that culture or institutions will move along the edges to vertices with higher fitness (analogous to climbing hills in the landscape). This represents small variation in existing designs of culture or institutions. Only those that are more fit are replicated into next generations. In the culture hypercube there are two peaks, 110 and 101, to which, depending on initial conditions, the design would evolve and then come to equilibrium as all one-mutant neighbors have lower fitness. Culture 110 is a local maximum and 101 a global maximum. The institutions hypercube also has a local maximum, 001, and a global maximum, 111.

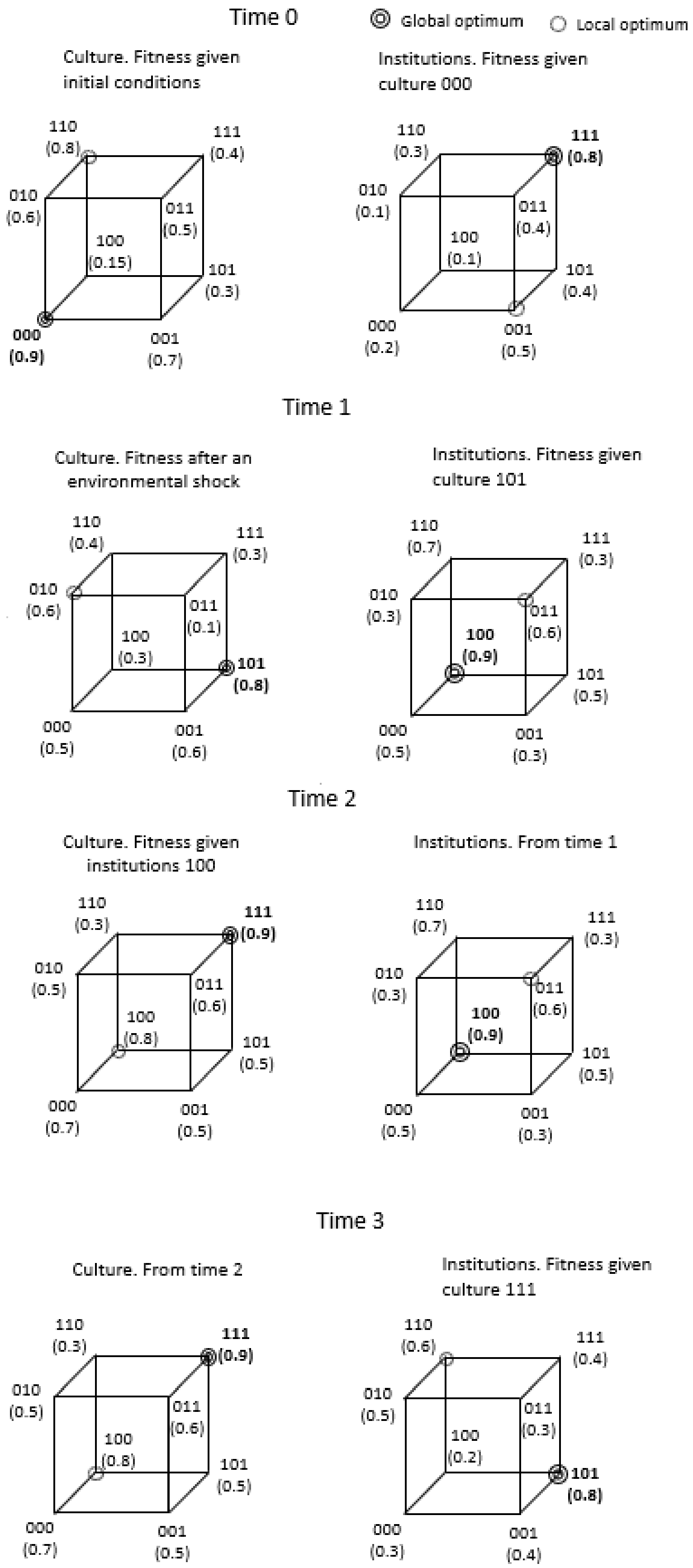
The coevolutionary dynamic between culture and institutions is represented by linking dimensions from one system to dimensions of the other. This is shown in Figure 3 as the dashed line linking dimension D3 of culture to dimension I2 of institutions. This link means that the fitness value of D3 is different if I2 is either 0 or 1. That is, institutions form part of the environment that selects for culture, and vice versa. The number of links determine how coupled the systems are, and once again a moderate number of constraints usually lead to more viable and interesting relations.

To envisage the characteristics of coevolutionary dynamics consider the configuration of possible designs of culture and institutions and associated fitness levels shown in Figure 4. Once again, the values are hypothetical. Suppose that a given society has evolved culture 000, that is, collectivist, tight and conformist, which is likely as this is a global maximum. In this example, this culture affects the fitness payoffs to different institutions, as shown in the first panel. Thus, either institutions 111 – extractive, common property, and state - or 001 – inclusive, individual property, and state – will evolve, depending on initial conditions for institutions. Suppose it is 111. This changes the fitness payoffs to culture, as shown in the second panel. Now the global and local optima are 101 and 010, respectively. Suppose culture changes to 101. This, in turn, induces a change in the fitness levels for institutions, with 100 and 011 now as optima. Suppose 100 evolves. This changes payoffs for culture as shown in the third panel. Now optimal cultures are 111 and 000 again, but suppose that this time culture 100 evolves. This then induces 101 and 110 as optimal institutions in panel 4.

This dynamic may continue churning in a Red Queen's Race, or it may settle in an evolutionarily stable equilibrium, at least until a shock changes fitness payoffs once again. The dynamic seems exasperating because it is not possible to predict or control what trajectory emerges. That is the point of the exercise. It shows how coevolution is subject to sensitivity to initial conditions, path dependence, non-optimality, multiple-equilibria, instability, uncertainty, mismatch, and non-ergodicity. Of course, the speed with which the coevolutionary dynamics operates depends on the nature and scale of the evolving units. With culture and institutions, it can be in the order of years or centuries. Also, we only see one of the 'runs' of the system, which may be an average run but may also be an exceptional one. In addition, I have abstracted from other systems that might simultaneously – but at different scales – be also coevolving with culture and institutions, such as technologies, geography, and language. With everything coevolving everywhere all the time, things become even more uncertain and capricious.[6]

[6] For an exercise that uses a five-dimensional hypercube for modelling the evolution of culture using actual GDP per capita data as a (imperfect) proxy for fitness, see Mueller (2021).

Figure 4 – Coevolution of culture and institutions



V. The coevolution of culture and institutions in the Great Enrichment

Ultrasociality and the collective brain

In this section I describe the Great Enrichment – the rise of modern economic growth – through an explicitly coevolutionary lens focusing on culture and institutions. How is it that in a backward region of the world conditions unexpectedly aligned that allowed some societies to overcome the negative feedbacks, the curse of concavity, and other dampening forces that had eternally quashed humanity's attempts to break free from inexorable Malthusian forces? This description is very much in the spirit of the hypercube model of coevolution, where depending on initial and boundary conditions some societies may have reached high fitness peaks (or vertices) while others got stuck in inferior local maxima. As in the case discussed above of the coevolution of farming and property rights (Bowles and Choi, 2013), neither the culture nor the institutions necessary for the transformation contained in the Great Enrichment could have evolved alone or separately. And there was nothing ineluctable that it had to happen. On the contrary, very small chance happenings along the way could have, as always, derailed this attempt to break free from the forces of negative feedback.[7]

To understand the coevolution of culture and institutions it is necessary to start with an evolutionary theory of human nature. The basic building block of such a theory is humans' ability for learning from others, that is the "ability to make inferences about the goals, preferences, motivations, intentions, beliefs and strategies in the mind of others" (Henrich, 2015: 50). Few other animals have these abilities and those that do have some sociality, do not come close to the ultrasociality of human beings. Much of the early genetic and cultural evolution of homo sapiens honed traits and features that facilitated and induced copying and learning form others, such as, the ability for language, theory of mind, mirror neurons, the white of the eyes (sclera), as well as psychological adaptations and norms for sharing, building coalitions within groups, and for choosing role models. Gene-culture coevolution since the start of the Homo genus, 2 million years ago, followed a dynamic where the evolution of genetic predispositions for learning enabled cultural enhancement thus enabling further genetic changes. According to Henrich (2015: 57) human exceptionality started relatively early when our species crossed what he calls the evolutionary Rubicon, that is, when culture became the primary driver of our species' genetic evolution.

[7] The account in this section is mostly based on the literature on cultural evolution, especially Henrich (2020, 2015), as well as Galor (2022), Mokyr (2016), Bowles and Gintis (2011), and Richerson and Boyd (2008).

Cultural learning is important because it takes new information discovered or created individually or in small groups and transmits it at no or low cost to others, thus entrusting it with the characteristics of a public good. Humans' cultural brain thus favors and enables innovation and progress. But if all this new information had had to be stored individually, the limited storage capacity of human brains would soon have limited the impact of social learning. However, after pursing many ways to increase individual brain capacity, such as big heads, soft skulls at birth, highly grooved and folded cortex, extended infancy and adolescence, gene-culture coevolution eventually turned to linking individual brains in networks that form a collective brain (Henrich, 2015, 2020).

Collective brains store different information in different heads and link those heads socially so that more information is available for other nodes in the network than that which they can gather individually. Collective brains are not just a sum of individual brains, rather they can, depending on the structure of the network, lead to synergies and positive feedback that can produce a remarkable and expanding body of cumulative culture even if the population is composed on average of individuals which are not particularly gifted or bright in most domains. Conversely, sparsely connected cultural brains with structures that hinder the flow of information serve as impediments to discovery and innovation.

The key to understanding why the Great Enrichment happened when and how it did, is to appraise history by considering the structure of the collective brain prevailing in this event compared to other instances when prosperity was either not achieved or was, only to subsequently fizzle out. The structure of the network tells us about the ease and likelihood that new knowledge will arise and then flow across the network. This depends on the incentives, aptitudes and attitudes for individuals or groups to incur the cost to produce new knowledge (individual learning) and once that information has been produced how easily it can be accessed by other nodes in the network. Three characteristics of the network determine its structure. First, larger groups have more people attempting to discover new information and greater ability to specialize across domains. The process of discovery and innovation is hard, and much of it is serendipitous, so larger groups are like playing the lottery more times. Second, norms, institutions, and cultural attitudes and beliefs can foster or impede new discoveries and transmission. Group homogeneity, ancestor worship, and conformism are examples of traits and group characteristics that not only can limit new knowledge from being produced but also reduce the fidelity of transmission, leading to a feebler collective brain. Third, the number of connections and strength of connection between nodes determine if the network is complex, and capable of producing novelty and surprise, rather than sclerotic or chaotic. Once again, it is certain configurations of culture and institutions that can lead the collective brain to the edge of chaos where interesting things happen.

Highly creative and fertile configurations are rare, so wherever they emerge, as in the case of the Great Enrichment, we want to know why or what conditions enabled that to happen. In most societies over history this either did not happen, or if it started to happen, it likely got smothered by the negative forces. During most of human history the dominant cultural package has been a collectivistic culture marked by strong kin-based norms that emphasize in-group sharing and cooperation, conformism, and loyalty to the group over individual autonomy and self-interest. Collectivist cultures' aversion and lack of trust towards strangers leads to an insularity that stymies the generation and transmission of information. This class of cultural traits arose early and dominated despite these shortcomings because they were particularly fit solutions for the nasty and brutish conditions encountered by human societies throughout history. Group cooperation, sharing, and suspicion of strangers, was a good strategy for survival and reproduction, though it did not enable these groups to free themselves from the dismal Malthusian forces to flourish. The fact that even today most humans live in societies that are predominantly collectivistic is evidence of the fitness value of this cultural package for survival and reproduction. The fact that most of these societies are poor is evidence that collectivism does not foster rapid innovation and long term economic growth.

However, very recently (in the grand scheme of human history) there emerged a different cultural package that has led to the dramatic transformations of the Great Enrichment. Individualistic cultures put the individual at the center of social life and emphasize personal autonomy, independence, and self-expression. Rather than limiting social and economic exchange to the extended family, clan or tribe, individualism centers life on the narrow nuclear family. Though this seems more limiting than the extended family, it inserts people in a broader social milieu where they interact with a more diverse set of partners and interlocutors outside of their immediate social network. To see why this matters, consider, as put by Henrich (2020: 443), "the difference between learning a crop rotation strategy from the best person in your extended family (a paternal uncle, say) or the best person in your town (the rich farmer with a big house)."

The larger and more connected collective brain is enabled culturally by traits such as generalized trust and morality (as opposed to in-group trust and morality) and institutionally by laws, property rights, courts, and other arrangements that support impersonal relations, exchange, and organizations. These cultural traits and institutional arrangements have been recognized as the fundamental determinants of the explosive rise in prosperity in the countries where they prevail. By encouraging entrepreneurship, competition, innovation, market exchange, individual rights, and freedoms, these individualistic societies have become WEIRD (western, educated, industrialized, rich and democratic), where the irony of the acronym refers to the fact that this is still a minor and atypical part to the world's population (Henrich, 2020).

In an evolutionary sense there is no presumption that one culture is preferable to any other, only that they vary in terms of their fitness to deal with the problems of survival and heritability given the environment. The question I wish to address using the lens of the coevolution of culture and institutions is to explain the transformation in parts of Western Europe and later in some of its offshoots, from collectivist societies struggling within the Malthusian logic and subject to the inexorable negative feedback of history, to individualistic cultures that achieved previously unimaginable levels of prosperity and innovation.

Negative feedbacks of history

The conceptual framework I use is to think in terms of the structure of the network when comparing historical events where a society managed to break free from the Malthusian trap to those where they did not. The hunter and gatherer groups that dominated over much of human history had strong in-group norms for sharing, cooperation, and group monitoring. These traits were important for survival in hostile environment and they facilitated the flow of information within the group. Hunter-gatherer societies' lack of formal leadership eliminated an important force against information hording and secrecy. In these conditions, human ultrasociality implied that new information discovered by any one member would flow to the collective brain. But these groups were of necessity small (typically a few dozen people) as larger groups make cooperation and collective action more difficult. Thus, the collective brain was small and limited. Eventual increases in knowledge and prosperity resulted in population increases that induced groups to split or secede. Culturally determined intergroup conflict, due to low out-group trust and morality, was an impediment to linking cultural brains across groups to make a larger and more potent cultural brain.[8] Even if losing groups were absorbed or if they emulated the more victorious, conditions worked against information-sharing networks.

[8] The validity of this claim has recently been contested by Graeber and Wengrow (2021) who argue that human prehistoric social organization was much more diverse and variable than what has previously been accepted. Their view remains controversial.

During the Neolithic Revolution climatic conditions induced the adoption of agriculture simultaneously in different areas of the world and it eventually spread almost everywhere. This change brought dramatic changes to human organization, including sedentism, state formation, cities, hierarchies, property rights, laws, taxes, enforcement, specialization, greater trade, among others. Importantly, it allowed for more larger populations and more complex social structures. In some ways these changes were conducive to a larger and more connected collective brain, and accordingly human inventiveness and accumulated knowledge did increase during this Axial Age and beyond.

But this progress was inexorably limited by the negative feedback naturally contained in the structures of the societies that were formed. With greater populations came more stratified and unequal societies organized in villages, kingdoms, states, and empires. These hierarchical forms of organization arose ubiquitously in the context of constantly warring societies. With them came hereditary warrior elites, priestly elites, and other forms of stratified caste and class systems. This kind of society, as noted by Ferguson (2017: 61), "was not a world where inventors were encouraged, but a world in which deviants were put to death … this was not a world where information flowed upwards or across, but one where it flowed downward, if at all." Cultural traits and norms coevolved with institutions to bolster the centralized and hierarchical structure and power relations that held them together. Though these varied across societies and contexts, they generally include elements of conformism, respect of authority, traditionalism, piety, ancestor worship, social rigidities, among others, all of which are compatible with collectivist cultures. Importantly for our purpose, all these traits contribute to limit the connectivity and fecundity of the collective brain. They activate the reactionary forces and fear of the new that have resisted change across history. Such conservative forces are often favored by evolutionary systems, as sticking to what is known to work can be a safer strategy than flying to others that we know not of.

An additional negative feedback that impeded the perpetuation of eventual episodes of prosperity was the constant threat of predation by invaders and plunderers from without, or by rent-seekers and corruption from within. Add to this what Mokyr (2016) has called the curse of concavity, that is, the decreasing returns to capital accumulation, trade, and other early sources of economic growth, and it is clear that despite the larger networks in the Dark Ages the structure of the collective brain in most places and contexts was not conducive to explosive innovation and exponential prosperity.

Given such a dismal scenario across practically all of human history, how was it that at some point something with a completely different dynamic would ensue? What is it that in some quarters suddenly enabled positive feedback to take over and prevail, with each new innovation expanding the adjacent possible and exponentially enabling more knowledge, innovation, and prosperity? Many answers to these questions have been postulated. Most nominate a silver bullet 'fundamental cause' such as technology, coal, geography, population growth, trade, and indeed, culture or institutions. While it is satisfying and often useful to have a parsimonious single defining idea to interpret the world, the coevolution of everything warns us that things are rarely that simple. The answer I describe to the question of the origins of the Great Enrichment is an explicitly coevolutionary interpretation that draws directly from a series of authors that have explicitly and implicitly championed Darwinian evolutionary theories that consider how the network structure of societies enable or impede how information emerges, is recombined and transmitted (Galor, 2022; Henrich, 2020; Schulz et al., 2019; Ferguson, 2017; McCloskey, 2016; Mokyr, 2016; Bowles and Gintis, 2011; Grief, 2006). Given the linear nature of writing, where one thing follows another, it is a challenge to properly describe coevolutionary processes that are non-linear, simultaneous, contingent, and endogenous. So, in what follows, if at any point it seems that one thing is linearly causing another, say institutions causing culture or vice-versa, keep in mind that it is a coevolutionary duet and eventually I'll highlight how one thing feeds back on the other.

Also keep in mind that the explanation here does not suggest that what happened was inevitable or even likely. As emphasized by the hypercube model from the previous section, coevolutionary processes have unpredictable dynamics, subject to tipping points, punctuated change and sensitivity to initial conditions, so what materialized could very well not have done so if history were repeated several times. In the same way that we don't interpret an estimated coefficient in a regression between two variables without considering a confidence interval to give us a notion of the likelihood of that estimate, in history it may be useful to think in terms of probabilities distributions over outcomes. As highlighted by McCloskey (1991), given nonlinearities in history small events that may not even have been noticed or recorded, that just might or not have happened, could have led to unanticipated consequences that shaped outcomes. This does not mean that we cannot say anything. Outcomes are "neither fluke nor destiny, but a balance of structure and contingency" (Fernandez-Villaverde et al. 2022: 3). The structure in the interpretation presented here is the collective brain, which modulates the "fluidity with which information flows through a population of engaged minds across generations" (Henrich, 2020: 440).

The Western Church's Marriage and Family Program

So what shock could have sent parts of Europe off the course of collectivism, intensive kinship and the perennial clutches of Malthusian forces and negative feedback? The answer, at first glance, is surprisingly unassuming. It has been traced to a series of reforms pursued by the Latin medieval Christian Church from the 9th to the 16th centuries that Henrich (2020) has called the Marriage and Family Program (MFP). This was not a unified and orderly program, but rather a complex and gradual assortment of changes to marriage practices that were part of the broader Gregorian Reforms that sought to assert clerical celibacy and to reduce the influence of secular rulers over church affairs. The MFP prohibited cousin marriage up to six degrees, disallowed polygamy, concubinage and divorce, and promoted free and mutual consent in marriage. These changes favored a nuclear family structure in which a husband and wife live together with their offspring, as opposed to the collectivist extended family that generally prevailed until then. To promote these changes newlyweds were encouraged to leave their parents' house after marriage to establish their own household. Although these changes were often resisted and varied in implementation and adoption in different times and places, by the 12th century the MFP was largely consolidated, firmly establishing the nuclear family as the normative family structure in Western Europe.

How can these important but relatively limited changes to marriage practices be the flap of the butterfly's wing that unleashed the Great Enrichment? So what if people could no longer marry their cousins or live with their parents? How could these tweaks to social mores and customs have set in motion the momentous transformations of the Renaissance, the Enlightenment, the Industrial Revolution, and the Great Enrichment? Clearly there were many forces simultaneously at work – everything coevolves. But it is useful to focus here on how the institutional changes of the MFP impacted the structure of the collective brain and induced changes in culture. If a young person living in a collectivist extended family can no longer marry a cousin, there is a strong inducement to leave for another place where the choice of mates is greater. Similarly, as long as newlyweds are to leave their parental habitation, chance are that they would seek to establish independently from the extended family or village, especially since the MPF changes to inheritance laws, such as primogeniture, also induced younger sons to drift. They also weakened the continuation of strong linages by obstructing their means to overcome occasional lack of heirs, such as polygamy, divorce, and adoption. By weakening lineages and kin-based norms and institutions, the MPF undermined centripetal collectivist forces and, over time, induced individuals and nuclear families to leave their extended families, lineages, villages, and their ancestral homelands and obligations to move to cities where they would substitute those previous ties by joining voluntary organizations such as companies, guilds, churches, learning societies, among others that allowed them to come together with aligned interest, thus boosting urbanization, specialization, and competition.

That is, these changes rewired the collective brain by breaking up secluded clusters in a sparse network and reconnecting them into a larger and more diverse, creative, and prolific structure. Over a few centuries, this larger and rewired structure induced dramatic cultural and psychological changes, such as greater impersonal trusts, less embeddedness in community, less deference to authority, less conformity, greater independence, more creativity and analytical thinking, that is, individualism instead of collectivism. These new beliefs, values, and attitudes further increased interconnectedness and produced new ideas, technologies, and institutions that made the collective brain even more complex. Technologically, the printing press dramatically transformed the flow of information along the network. It is interesting that the printing press had already been invented by the Chinese and Koreans, where its impact was subdued, which highlights the complementary importance of cultural readiness for modulating not just the rise, but the impact of new technologies and ideas.

Although the switch from collectivism freed people from the bonds of intensive kinship’s constraints, it also dispensed with the protection, solidarity, community, and sense of belonging of the extended family. Individualistic cultures had to attend to these needs by other means. What emerged were formal institutions such as laws, individual rights, property rights, courts, police, law merchant, religious organization and charities, among others. In addition, a variety of other organizations emerged to accommodate different individual and social needs and interests, such as, apprenticeship institutions, guilds, transregional monastic orders, universities, knowledge societies, and a host of common interest organizations that people could voluntarily join, such as Freemasons and Rosicrucians, coming into contact with people who were not otherwise part of their social networks.

Together the individualistic cultural values – impersonal trust, fairness, and prosociality - and the formal institutions that undergirded impersonal markets, represented a complete rewiring of the collective brain and its ability to generate and transmit information. These changes increased the rate and caliber of recombination of existing knowledge leading to exponential inventiveness and unparalleled economic prosperity. Because the cultural and psychological shift towards individualism included a focus on child quality rather than quantity, leading to smaller families, the Malthusian logic was severed and economic growth was not diluted this time by increases in population. For the first time a positive feedback logic of ideas begetting ideas overpowered the immemorial negative feedback dynamic.

The Republic of Letters

Why did this process take place in Europe and not elsewhere? It is not the case that Europe was exceptional or predestined and that the growth in knowledge somehow could only be a European phenomenon. At several points in history processes of cultural and scientific flourishing materialized in places like China, India or the Islamic world, which were far more advanced than Europe. These were instances in which the Great Enrichment phase transition may almost have taken place, but just barely fell short. This problem has come to be known as the Needham Question, after historian Joseph Needham who asked "why modern science had not developed in Chinese civilization (or Indian) but only in Europe, … (as) between the first century BC and the fifteenth century AD, Chinese civilization was much more efficient than occidental in applying human natural knowledge to practical human needs" (Needham, 1969).

The failure of Chinese science and technological advances to persist is not surprising given the negative feedback dynamics of history. This tendency of historical instances of creativity and effervescence to fizzle out as reactionary and conservative forces block further challenges to entrenched knowledge and ideas is known as Cardwell's Law (Cardwell, 1971; Mokyr, 1994). According to Mokyr (2016: 288):

> What was exceptional was not what happened in China but what happened in Europe, where no such retrenchment occurred. Not only did the growth of useful knowledge not run into a barrier that stopped it in its tracks, but European methods for acquiring, vetting, disseminating, and applying it spread world-wide and eventually disrupted the equilibria that had settled in the Middle East, in China, and elsewhere.

Mokyr's account of how Europe managed to accomplish this phase transition, overcoming the Malthusian ceiling and reactionary negative feedback, is rooted in a coevolutionary logic where culture and institutions changed in tandem, each carving out toeholds for the other to continue evolving. The transition required both a cultural change in belief and attitudes as well as supporting institutions that perpetuated those values and catalyzed the transformation of propositional knowledge (science and theoretical understanding) into prescriptive knowledge (practical skills and techniques), which, by the way, also interact coevolutionarily.

The crucial cultural change was what Joel Mokyr has termed a belief in useful knowledge. This was a belief that human intellectual and practical endeavor should seek to uncover and develop knowledge that has practical applications for understanding the world around us and for solving specific problems that improve human well-being. It is different from the then prevailing concern with knowledge as a means of understanding the divine or achieving spiritual enlightenment. It was also a departure from the classical Greek and Roman canon that dominated intellectual life in Middle Age Europe. Together these two incumbent cultural outlooks exerted strong reactionary forces that stifled innovation and exploration. Part of the attitude inherent in the belief in useful knowledge was precisely a disrespect to these dominating bodies of thought, and thus a rebellious willingness to push into the adjacent possible.

One may wonder why a cultural package so propitious to creativity and innovation emerged in Europe and not elsewhere. But before Europe several other instances of intellectual flourishing had emerged but fizzled out, such as in the Song Dynasty in China, Gupta Empire in India, Greek and Roman Empires, and the Islamic Golden Age. What differed in Europe was that the new beliefs managed to resist the backlash from entrenched interests and dogmas that tried to stifle them from expanding and spreading. It is not that opposing forces did not exist in Europe. The Catholic Church, all sorts of rulers, landed gentry, and even guilds and laborers perceived the new beliefs as threats to their rents and resisted in different ways. Universities, in the early period, for example, where more likely to guard tradition and the intellectual status quo than to promote curiosity and experimentation. What was different in Europe were special circumstances that enabled those who produced new useful knowledge to evade and circumvent the repressive backlash.

Unlike China and other flourishing empires, Europe was never a unified and centralized state where administrative and political centralization could successfully enact a homogenous and effective repressive response to heretical and rebellious ideas. Europe was politically fragmented, composed of numerous independent states, territories, principalities, communes, city states, and other forms of agglomeration, each with their own distinct cultures, languages, laws, and customs. While the influence of the Holy Roman Church was present over much of the territory, it was itself internally fragmented and was unable to act as a unifying force over this fragmented political landscape. Political fragmentation implied a plurality of views, beliefs, and interest. This does not mean that there was tolerance and open-mindedness for new ideas and behaviors. However, it does mean that whenever ideas and behaviors were met with resistance in any one place, their creators could easily find other places to which they could flee or seek exile, where the same ideas would not be met with resistance. There was an intense cross migration of the intellectual elite throughout the

Enlightenment and beyond: Voltaire, Galileo, Diderot, Goethe, Montesquieu, and many others were either exiled or forced to flee to more sympathetic lands. Some, such as Giordano Bruno, were burned for their views, and others were imprisoned, condemned or excommunicated. But these were exceptional cases. The availability of safe havens and like-minded allies in other regions frustrated most attempts at repression and "by the middle of the eighteenth century it is fair to say that even in so-called absolutists countries, the suppression of dissenting and even heretical voices had become more of a ritualized formality than a real threat" (Mokyr, 2016: 178).

Yet while some form of belief in useful knowledge is a necessary condition for the Great Enrichment it is not sufficient. Remember that the inventiveness of a society depends on the size and structure of the collective brain. If political and geographic fragmentation enabled new ideas to emerge and survive, it militated against the capacity of those ideas being transmitted, evaluated, recombined, and tried out in multiple ways, which is the essential next step for the production of knowledge and prosperity. Diverse new ideas would have little impact if they remained confined to the small and few fragmented regions where they were not prosecuted. So, the next key ingredient in the process of European Enlightenment was a means to connect all the participants of the intellectual elite, writers, thinkers, scholars, and practitioners, in a transnational network fueled by the belief in useful knowledge and a commitment to intellectual curiosity and the spread of new ideas, that could transmit and irradiate ideas being produced in every quarter. The institution that fulfilled this purpose was the Republic of Letters, a network of correspondence where new ideas, inventions, and discoveries would be announced and discussed. It ran on a Baconian ethic of scientific inquiry based on the observation of nature and collection of empirical facts and data, and the use of experimentation to draw conclusions based on results, thus creating a shared body of knowledge constantly refined through challenges and possible refutation by even newer ideas. Incentives to participate were not directly pecuniary, but based on reputation, as the Republic of Letter assigned propriety to those who first produced successful new knowledge, i.e. Newton's Laws of motion, Bayes Theorem, Lagrange multipliers, and Darwin's Theory of Natural Selection.

The Republic of Letters was quite literally a rewiring of the collective brain. It created scale despite diversity. It also encouraged dissent and exploration because of diversity. And once it was in place and operational it broke through the forces of repression and engaged the forces of positive feedback, where discovery of new natural phenomena in any given area, or new ideas and perspectives, increased the set of cumulative culture available to recombine and produce a combinatorically expanding corpus of new useful knowledge, resulting in the Industrial Revolution and the remarkable advances in knowledge and material well-being observed in the 19th century and beyond.

VI. Concluding Remarks

As I anticipated, the description here of how Europe managed, starting in the early modern period, to transition from an ineludible Malthusian equilibrium to the Great Enrichment, risks sounding linear, causal, and preordained. An institutional change – the Church's Marriage and Family Program – led to a cultural change – individualism and a belief in useful knowledge - that led to an institutional change – the Republic of Letters – which generated new ideas and discoveries that produced wealth and prosperity. In retrospect it is hard to avoid the feeling that this course of action was bound to happen when it did, for only then was everything in place, and that it could not have happened elsewhere, as elsewhere those very same elements were missing.

Instead, I have suggested that this process was coevolutionary, with changes in culture and institutions mutually and simultaneously affecting the fitness payoffs for how each system evolves individually, as each composes part of the selecting environment of the other. The landscape model used to analyze the nature of coevolutionary processes showed how they are characterized by several properties that elude control or prediction. Coevolutionary systems are sensitive to initial conditions, subject to uncertainty, instability, path dependence, but also criticality, tipping points and unannounced phase transitions. We try to make sense of what happened, once we get the full picture, but in the eagerness to tell a coherent story, risk making history into a just-so story. Coevolutionary systems process information and in complex systems information doesn't play nice, making what happened hard to fit in a linear, causal, explainable narrative.

Although I started the narrative with the Marriage and Family Program breaking up clans and extended family, by then the coevolution of institutions and culture had already been churning for millennia. Outcomes at any point are sensitive to initial conditions, and in history there are almost always earlier initial conditions. We have to start somewhere and take initial conditions as given, but that always leaves questions, for example, why the Western Church pursued this line of action when and how it did. As Mokyr notes to conclude his book *A Culture of Growth*, the rise of modern science and technology in Europe is at the same time the natural continuation of ancient medieval and Renaissance culture, but also, paradoxically, its repudiation:

> There was nothing inexorable about this turn of events; indeed, it was a closely fought outcome. Fairly minor rewrites of history could have secured Europe for an obscurantist Catholic regime in which the Republic of Letters would have turned into a benighted theocracy… (Mokyr, 2016: 341)

This indeterminacy riles standard expectations that everything must be reasoned out and accounted for. In coevolutionary and complex systems, however, a better approach may be to think in terms of distributions of outcomes that emerge from different runs of the systems, or in Mokyr's terms, 'fairly minor rewrites of history'.

References

Acemoglu, D., & Robinson, J. A. (2021). *Culture, institutions and social equilibria: A framework* (No. w28832). National Bureau of Economic Research.

Acemoglu, D., Johnson, S., & Robinson, J. A. (2001). The colonial origins of comparative development: An empirical investigation. *American Economic Review*, *91*(5), 1369-1401.

Alesina, A., & Giuliano, P. (2015). Culture and institutions. *Journal of Economic Literature*, *53*(4), 898-944.

Alesina, A., Giuliano, P., & Nunn, N. (2013). On the origins of gender roles: Women and the plough. *The Quarterly Journal of Economics*, *128*(2), 469-530.

Ashraf, Q., & Galor, O. (2013). The "Out of Africa" hypothesis, human genetic diversity, and comparative economic development. *American Economic Review*, *103*(1), 1-46.

Beugelsdijk, S., & Maseland, R. (2010). *Culture in economics: History, methodological reflections and contemporary applications*. Cambridge University Press.

Bisin, A., Rubin, J., Seror, A., & Verdier, T. (2021). *Culture, Institutions & the Long Divergence* (No. w28488). National Bureau of Economic Research.

Bisin, Alberto, Avner Seror, and Thierry Verdier (2019) "Religious legitimacy and the joint evolution of culture and institutions," in Advances in the Economics of Religion: Springer, pp. 321–332.

Bisin, A., & Verdier, T. (2021). Phase diagrams in historical economics: culture and institutions. In *The Handbook of Historical Economics* (pp. 491-522). Academic Press.

Bisin, A., & Verdier, T. (2017). *On the joint evolution of culture and institutions* (No. w23375). NBER Working Paper Series: National Bureau of Economic Research.

Bisin, A., & Verdier, T. (2005). Cultural transmission. *The New Palgrave Dictionary of Economics*.

Bisin, A., & Verdier, T. (2001). The economics of cultural transmission and the dynamics of preferences. *Journal of Economic theory*, *97*(2), 298-319.

Boserup, E. (1970). *Woman's Role in Economic Development*, London: George Allen and Unwin Ltd.,1970.

Bowles, S., Choi, J. K., Hwang, S. H., & Naidu, S. (2021). How institutions and cultures change: an evolutionary perspective. *The Handbook of Historical Economics*, 391.

Bowles, S., & Choi, J.-K. (2019). The neolithic agricultural revolution and the origins of private property. *Journal of Political Economy*, 127 (5), 2186-2228.

Bowles, S., & Choi, J. K. (2013). Coevolution of farming and private property during the early Holocene. *Proceedings of the National Academy of Sciences*, *110*(22), 8830-8835.

Bowles S, Choi J.K., Hopfensitz A. (2003). The co-evolution of individual behaviors and social institutions. *Journal of Theoretical Biology*.;223(2):135-147.

Bowles, S., & Gintis, H. (2011). *A Cooperative Species*. Princeton University Press.

Cardwell, D. S. L. (1972). *Turning points in western technology; a study of technology, science and history*. New York: Science History Publications.

Choi J.K., Bowles S. (2007). The coevolution of parochial altruism and war. *Science*. 318(5850): 636-640.

Delong, B. (2003). *Estimating world gdp, one million bc-present. department of economics*, University of California, Berkeley. https://www.bradford-delong.com.

DiMaggio, Paul (1997) "Culture and cognition," Annual Review of Sociology, 23, 263-287.

Djankov, S., Glaeser, E., La Porta, R., Lopez-de-Silanes, F., & Shleifer, A. (2003). The new comparative economics. *Journal of Comparative Economics*, *31*(4), 595-619.

Ferguson, N. (2017). *The square and the tower: networks, hierarchies and the struggle for global power*. Penguin UK.

Fernández-Villaverde, J., Koyama, M., Lin, Y., & Sng, T. H. (2023). The fractured-land hypothesis. *The Quarterly Journal of Economics*, *138*(2), 1173-1231.

Galor, O. (2022). *The Journey of Humanity: The origins of wealth and inequality*. Penguin.

Gelfand, M. J., Raver, J. L., Nishii, L., Leslie, L. M., Lun, J., Lim, B. C., . . . others (2011). Differences between tight and loose cultures: A 33-nation study. *Science*, 332 (6033), 1100-1104.

Geertz, C. (1973). *The Interpretation of Cultures.* New York: Basic Books.

Graeber, D., & Wengrow, D. (2021). *The dawn of everything: A new history of humanity*. Penguin UK.

Greif, A. (1989): Reputation and Coalitions in Medieval Trade: Evidence on the Maghribi Traders, *Journal of Economic History*, 49(4), 857-882.

Greif, A. (1994): Cultural Beliefs and the Organization of Society: A Historical and Theoretical Reflection on Collectivist and Individualist Societies, *Journal of Political Economy*, 102(5), 912-50.

Greif, A. (2006). *Institutions and the path to the modern economy: Lessons from medieval trade*. Cambridge University Press.

Greif, A. and G. Tabellini (2017). .The Clan and the Corporation: Sustaining Cooperation in China and Europe, *Journal of Comparative Economics*. 45, 1.35.

Hayek, F. A. (1944). *The Road to Serfdom.* Chicago: University of Chicago Press.

Henrich, J. (2020). *The weirdest people in the world: How the west became psychologically peculiar and particularly prosperous*. Farrar, Straus and Giroux.

Henrich, J. (2015). *The Secret of Our Success*. Princeton University Press.

Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world? *Behavioral and brain sciences*, 33 (2-3), 61-83.

Hofstede, G. (2011). Dimensionalizing cultures: The Hofstede model in context. *Online readings in psychology and culture*, 2 (1), 2307-0919.

Hubálek, M. (2021). A brief (hi) story of just-so stories in evolutionary science. *Philosophy of the Social Sciences*, *51*(5), 447-468.

Johnson, S. D., & Anderson, B. (2010). Coevolution between food-rewarding flowers and their pollinators. *Evolution: Education and Outreach*, *3*(1), 32-39.

Kauffman, S. (1993). *The origins of order: Self-organization and selection in evolution*. Oxford University Press, USA.

Kafka, K. I., Kostis, P. C., & Petrakis, P. E. (2020). Why Coevolution of Culture and Institutions Matters for Economic Development and Growth? In *Perspectives on Economic Development-Public Policy, Culture, and Economic Development*. IntechOpen.

Lowes, S., Nunn, N., Robinson, J. A., & Weigel, J. L. (2017). The evolution of culture and institutions: Evidence from the Kuba Kingdom. *Econometrica*, *85*(4), 1065-1091.

Lowes, S. (2022). *Culture in Historical Political Economy.* In eds. J. Jenkins and J. Rubin, *Oxford Handbook of Historical Political Economy*. Oxford University Press. 10.1093/oxfordhb/9780197618608.001.0001

McCloskey, D. N. (2016). *Bourgeois equality: How ideas, not capital or institutions, enriched the world* (Vol. 3). University of Chicago Press Chicago.

McCloskey, D. N. (1991). History, differential equations, and the problem of narration. *History and theory*, *30*(1): 21-36.

Mokyr, J. (2016). *A culture of growth: the origins of the modern economy*. Princeton University Press.

Mokyr, J. (1994). Cardwell's Law and the political economy of technological progress. *Research Policy*, *23*(5), 561-574.

Mueller, B. (2021). How Culture Evolves: Measuring Cultural Distance and Variation. *Available at SSRN 3819833*.

Mueller, B. (2018). The coevolution of institutions and culture. In *A Research Agenda for New Institutional Economics* (pp. 153-161). Edward Elgar Publishing.

Mueller, B., & Ayello Leite, J. G. (2020). How the East was lost: Coevolution of institutions and culture in the 16th century Portuguese empire. *Available at SSRN 3548654*.

Needham, J. (1969). Science and Society in East and West. In *The Grand Titration: Science and Society in East and West*. By Joseph Needham, 190–217. London: Allen & Unwin.

North, D.C. (2005). *Understanding the Process of Economic Change*. Princeton University Press.

North, D. C., &Weingast, B. R. (1989). Constitutions and commitment: the evolution of institutions governing public choice in seventeenth-century England. *The Journal of Economic History*, 49 (4), 803-832.

Nunn, N. (2021). History as evolution. In *The Handbook of Historical Economics* (pp. 41-91). Academic Press.

Nunn, N. (2022). On the dynamics of human behavior: The past, present, and future of culture, conflict, and cooperation. In *AEA Papers and Proceedings* (Vol. 112, pp. 15-37).

Odling-Smee, J., Erwin, D. H., Palkovacs, E. P., Feldman, M. W., & Laland, K. N. (2013). Niche construction theory: a practical guide for ecologists. *The Quarterly review of biology*, *88*(1), 3-28.

Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge university press.

Parsons, T. (1951). The Social System, New York: Free Press.

Persson, T., & Tabellini, G. (2021). Culture, institutions, and policy. In *The Handbook of Historical Economics* (pp. 463-489). Academic Press.

Pomeranz, K. (2000). *The great divergence: China, Europe, and the making of the modern World economy*. Princeton University Press.

Richerson, P. J., & Boyd, R. (2008). *Not by genes alone: How culture transformed human evolution*. University of Chicago Press.

Ridley, M. (2016). *The Evolution of Everything: How Small Changes Transform Our World*. London, Great Britain: 4th Estate.

Schulz, J. F., Bahrami-Rad, D., Beauchamp, J. P., & Henrich, J. (2019). The Church, intensive kinship, and global psychological variation. *Science*, *366*(6466), eaau5141.

Schwartz, S. H. (2006). A theory of cultural value orientations: Explication and applications. *New frontiers in comparative sociology*, 173-220.

Smith, A. (1950). *An inquiry into the nature and causes of the wealth of nations*,(1776). Methuen.

Sokoloff, K. L. and S. L. Engerman. 2000. Institutions, Factor Endowments, and Paths of Development in the New World. *Journal of Economic Perspectives*, 14 (3): 217-232.

Tabellini, G. (2008). The scope of cooperation: Values and incentives. *The Quarterly Journal of Economics*, *123*(3), 905-950.

Turchin, P., Currie, T. E., Whitehouse, H., Francois, P., Feeney, K., Mullins, D., et al. (2018). Quantitative historical analysis uncovers a single dimension of complexity that structures global variation in human social organization. *Proceedings of the National Academy of Sciences*, 115 (2), E144-E151.

Voth, H. J. (2021). Persistence–myth and mystery. In *The Handbook of Historical Economics* (pp. 243-267). Academic Press.

Watts, D. J. (2011). *Everything is obvious: Once you know the answer*. Currency.

Whitehouse, H., Francois, P., Savage, P. E., Currie, T. E., Feeney, K. C., Cioni, E., et al. (2019). Complex societies precede moralizing gods throughout world history. *Nature*, 568 (7751), 226-229.

Wright, S. (1932). The roles of mutation, inbreeding, crossbreeding, and selection in evolution (Vol. 1). *Proc. 6th Int. Cong. Genetics*.