A Culture of Growth

The Origins of the Modern Economy

The Graz Schumpeter Lectures

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Chapter 1

Culture and Economics

The world today is richer than it has ever been. We know a great deal about the economic transformations that made it this way thanks to a vast literature examining every possible aspect of modern economic growth taking place since ca. 1800. We know *what* happened, and we know more or less *how* and *where* it happened. What remains very much a mystery is *why*. This book tries to provide an answer.

The basic facts are not in dispute. The British Industrial Revolution of the late eighteenth century unleashed a phenomenon never before even remotely experienced by any society. Of course, innovation has taken place throughout history. Milestone breakthroughs in earlier times—such as water mills, the horse collar, and the printing press—can all be traced more or less, and their economic effects can be assessed. They appeared, often transformed an industry affected, but once incorporated, further progress slowed and sometimes stopped altogether. They did not trigger anything resembling sustained technological progress, and their effects on income were small and in many cases barely enough to offset population increase. As late at 1754 David Hume summarized the economic history of the world until that time by noting that "if the general system of things, and human society of course, have any ... gradual revolution, they are too slow to be discerned in that short period. ... Stature and force of body, length of life, even courage and genius, seem hitherto to have been in all ages pretty much the same" (Hume [1754] 1985, p. 378). As a description of the past, Hume's summary is consistent with much of the consensus in economic history today (leaving aside, perhaps, courage, on which little has been said).

But as a prognostication of what was to come, this turned out to be spectacularly incorrect, and Hume was wise to add the qualification "hitherto." The early advances in the cotton industry, iron manufacturing, and steam power of the years after 1760 became in the nineteenth century a self-reinforcing cascade of innovation, one that is still very much with us today and seems to grow ever more pervasive and powerful. If economic growth before the Industrial Revolution, such as it was, was largely driven by trade, more effective markets and improved allocations of resources, growth in the modern era has been increasingly driven by the expansion of what was known in the age of Enlightenment as "useful knowledge."

What had started in a few counties in the English midlands and the Scottish lowlands soon spread to the European continent and to America. By the end of the nineteenth century, the Industrial Revolution had transformed the economies of much of Europe and the European offshoots, and it began to spread to Japan and other non-Western economies. Transformative technological change turned from an unusual and remarkable phenomenon to something routine, expected. By 1890, one might not know what kind of and where a wave of technological progress would erupt, but one got accustomed to *something* happening. The results were inescapable: nearly everywhere on the planet men and women lived longer, ate better, enjoyed more leisure, and had access to resources and delights that previously had been reserved for the very rich and powerful, or more commonly, had been utterly unknown. With these blessings came disruptions, environmental disasters, and at times utter destruction. Technology and economic might provide the human race with more powerful tools, nothing more. Today, although the rate of measured economic growth in the industrialized world has slowed down, such blessings and curses are still piling up. Measured economic growth in the industrializing economies in the nineteenth and twentieth centuries approached a rate of 1.5–2.0 percent a year, perhaps ten times faster than before. Moreover, the resulting prosperity turned out to be persistent. Despite a series of self-inflicted political and economic disasters in the twentieth century, the industrialized West recovered miraculously after 1950 and was able to reach living standards that would have been unthinkable in 1914, let alone in 1800.

There can be no doubt that growth of this kind, while of global consequences, started in the West. What used to be known as the literature on "the rise of the west" or "the European Miracle" (following E. L. Jones's seminal 1981 book)—now more commonly referred to as "the Great Divergence" or "the Great Enrichment"—documents and describes the West's leadership in the emergence of Modern Growth. But a consensus on why this happened seems remote.[1] Some scholars have branded the writings of those who point to the Western origins of modern

[1] In a recent tour d'horizon, Peer Vries (2013) has surveyed many explanations offered over the years for the origins of the Great Divergence and the escape from poverty. In the end, however, he finds the bulk of them unpersuasive, and even the ones he favors seem to lack precision and are hard to test.

economic growth as "Eurocentric," implying that such explanations suggest some kind of inherent superiority of European culture or institutions. While it is undeniable that some accounts have tried to credit some aspect or other of Western civilization, most scholars have eschewed such simple arguments and tried either to avoid cultural explanations altogether or to come to grips with the question of why certain values and beliefs differed systematically. One can write such histories without sounding "triumphalist" (Goldstone, 2012). The account below should be seen as part of this tradition.

In this book, I propose a new explanation, largely based on events in Europe. It is one that relies on something I call "culture," but unlike most accounts that rely on this vague concept, the notion of culture I deploy will be circumscribed and defined with precision. The great economist Robert Solow once remarked that all attempts to explain differences in economic performance and growth using culture "end up in a blaze of amateur sociology" (quoted in Krugman, 1991, p. 93, n. 3). Perhaps. But if we are to look for institutions to explain historical development, can culture be far behind?

My approach simultaneously resolves two difficulties in the "Great Divergence" literature, one historical and one economic. The *historical* riddle is what might be called the great dilemma of the new institutional economic history: much of the literature in economic history that is trying to explain differences in economic performance and living standards, both by economists and historians, has accepted in one way or another Douglass North's call for the integration of institutions into our narrative of economic growth (Acemoglu and Robinson, 2012; Sened and Galiani, 2014). An economy that grows as a result of favorable institutions requires a world of well-delineated and respected property rights, enforceable contracts, law and order, a low level of opportunism and rent-seeking, a high degree of inclusion in political decision making and the benefits of growth, and a political organization in which power and wealth are as separate as is humanly possible. Such institutions—whether part of the formal political structure (as embodied for example in a constitution) or based on private-order institutions—are credited with many positive economic developments in the past: the rise of more effective product and factor markets (and thus more efficient allocations), the growth of international and interregional trade, and the accumulation of capital, to name a few. But, as other scholars (Vries, 2013, p. 433; McCloskey, 2016b) have argued, the puzzle is that better markets, more cooperative behavior, and more efficient allocations simply do not in themselves account for modern economic growth. What is far harder to explain is the growth of technological creativity and innovation in Europe and especially the surge following the middle of the eighteenth century. The Industrial Revolution, in the sense of an acceleration of technological progress, at first blush does not seem to have been a response to any obvious institutional stimulus. We actually know remarkably little about the kind of institutions that foster and stimulate technological progress and more widely, intellectual innovation.

The second riddle is closely related but looks at the problem from a different, more economic, point of view. If the generation and continuous improvement of new "useful knowledge"—both scientific and technological—is at the core of modern economic growth, the riddle is one of motivation or incentives. Knowledge, as has long been understood, is an unusual commodity, subject to rather serious public good properties: it is very hard to exclude others from using it, and the cost to the owner from sharing it is negligible or zero. As a result, economists suspect that knowledge tends to be chronically underproduced, because those who spend resources, time, and effort generating it have difficulty appropriating any returns. As far as technology or prescriptive knowledge is concerned, the existence of a patent system or other ways to reward inventors has provided a (very) partial solution.[2] But advances in natural philosophy and propositional knowledge could not be patented. This is especially problematic because the growth of technological knowledge by itself, without the constant interaction with some form of formal or informal science, would not have been able to generate growth and development at the rates observed. The issue of the exact role of science in the Industrial Revolution is still debated, but there can be no doubt that as growth accelerated, the input from science increased and became the dominant motive power at some point after 1830.

As this book makes clear, the solutions to the historical and the economic riddles coincide. My focus is on the period from 1500 to 1700, during which the cultural foundations of modern growth were laid. These foundations grew out of a set of political and institutional developments and cultural changes that were not intended to produce these results, and their deeply contingent nature is a recurrent theme in these pages.

A famous distinction made in Jewish law illustrates the difference between the type of phenomena we associate with institutions, on the one hand, and the importance of process and product innovation fed by growing human knowledge of natural forces on the other. The Talmudic tradition distinguishes between affairs that concern relations between the individual and others, and the relations between the individual and *makom*—a somewhat unusual name for the deity, meaning literally "place"

[2] For an assessment of the patent system in the early stages of economic growth in Europe, see Mokyr (2009b).

and practically interpreted as one's physical environment.[3] Commerce, the division of labor, effective markets in labor, credit and land, and similar institutions associated with Smithian growth were all outcomes of games between people. They depended on what values people adhered to and what they believed about others' values and behavior. What is less discussed is a set of cultural beliefs that pertain to games against *nature*, in which individuals try to understand natural regularities and exploit them to their advantage. Religious beliefs and metaphysical attitudes condition a society's willingness to investigate the secrets of nature, alter its physical environment irreversibly, and "play God." Technology is at its very core a relation of people with the physical environment and not with other people. For such practical matters as the diffusion and implementation of new techniques, of course, social relations are central to technological progress. But in the end the willingness to challenge nature in some way to reveal one of her secrets is based on metaphysical beliefs held at the individual level.

The drivers of technological progress and eventually economic performance were attitude and aptitude. The former set the willingness and energy with which people try to understand the natural world around them; the latter determines their success in turning such knowledge into higher productivity and living standards.[4] In this book I will be concerned with attitudes. The proposition I put forward here is that the explosion of technological progress in the West was made possible by cultural changes. "Culture" affected technology both directly, by changing attitudes toward the natural world, and indirectly, by creating and nurturing institutions that stimulated and supported the accumulation and diffusion of "useful knowledge." For quite a few years now, economists have become increasingly open to the idea that long-term economic change cannot be seriously analyzed without some concept of "culture" and some idea of how it changes and why these changes matter. McCloskey's massive trilogy (2006, 2010, 2016a) is by far the most significant of these analyses, but many mainstream economists are now committed to the significance of culture in the evolution of modern economies.[5] The reason this is so has been ob-

[3] This distinction has also found its way into the writings of Freud, who notes that "civilization" describes the sum of achievements that serve two types of purposes: "to protect men against nature, and to adjust their mutual relations" (Freud, [1930] 1961, p. 36).

[4] Differences in aptitude explain, for instance, why the Industrial Revolution started in Britain and not elsewhere in Europe (Mokyr, 2009a; Kelly, Mokyr, and Ó Gráda, 2014).

[5] Two particularly interesting examples are Doepke and Zilibotti (2008) and Clark (2007). Both stress the growth of certain cultural features associated with entrepreneurial behavior such as hard work and willingness to postpone gratification, and explicitly stress how these features are passed on from generation to generation. For a recent survey, see Alesina and Giulano (2016).

vious for a long time. Individuals are assumed to have preferences and beliefs that determine how they are likely to act both toward others and toward their natural environment. However, these cultural elements can change, and we want to know why they change, and why at times culture changes at a tectonic pace, and at others with startling rapidity (Jones, 2006). But "culture" is a vague and mushy word, and as such is not a satisfactory term: here we need to be much more specific about whose culture and what specific elements of it mattered. Moreover, we must understand how culture changes and why societies have different cultures. If economists cannot contribute to this literature, they should leave it to other social scientists, but in that case they must concede much of the explanation of modern economic growth to others. An alternative is to see what historians and students of "culture" (in a certain sense) have had to say and incorporate their insights into the economic narrative (Vries, 2001).

To start with: Culture means various things to different people, and to begin, we need to clarify the concept and our use of it. Given the rather astonishing popularity of the concept of culture in the social sciences and the humanities and the mind-boggling number of definitions employed, it is useful for an economist to start off by defining precisely what is included in and excluded from "culture" and how it differs from "institutions," before we examine its role in the origins of modern economic growth.[6] The definition I use here (and one very similar to the definition proposed by Boyd and Richerson, 1985, p. 2) is: *Culture is a set of beliefs, values, and preferences, capable of affecting behavior, that are socially (not genetically) transmitted and that are shared by some subset of society.* In what follows, my approach is similar to and inspired by the literature on cultural evolution proposed by some anthropologists. It will have little in common with "cultural studies" and the cultural analysis implied by social constructivism.

What does this definition buy us? First, **beliefs** contain statements of a positive (factual) nature that pertain to the state of the world, including the physical and metaphysical environments and social relations.[7] Second, **values** pertain to normative statements about society and social relations (often thought of as ethics and ideology), whereas **preferences** are normative statements about individual matters such as consumption and personal affairs. Third, culture is decomposable, that is, it consists of separate cultural elements or features. Much like genes, these traits are

[6] In a famous essay, Kroeber and Kluckhohn (1952) assembled no fewer than 156 different definitions of the term culture. It goes without saying that since then the term has been used and abused in different contexts by social scientists and historians, so that the number of different definitions would be larger today.

[7] As such, "beliefs" should be interpreted as containing knowledge, both codifiable and tacit, as well as human skills and capabilities. The most important component of these beliefs for my purpose is useful knowledge.

largely shared by people of the same culture; a single individual cannot have a cultural trait that is not shared by others, but each individual is unique in that it is highly unlikely that two people share precisely the same combination of cultural elements. There is no puzzle here: by analogy, all individuals have somewhat different genotypes (identical twins excluded) yet they share the vast bulk of their genes with other people and even with other mammals that have quite different phenotypes. Furthermore, this definition stresses that culture involves social learning, so that one's beliefs, values, and knowledge are not built-up from scratch for each individual but are acquired from others. The key concepts of attitude and aptitude are contained in the larger category of culture, and they will remain at the center of the discussion.

One could argue whether *behavior* itself (that is, actions) should be included in the concept of culture, but it seems useful to separate actions (which may be driven by a combination of cultural and other causes) from culture that guides and constrains it, although a great deal of culture, much like junk DNA that does not code for any known proteins, just "is" there in our minds and conditions no actions. The use of these evolutionary terms suggests an analogy that treats culture as genotypical and actions as phenotypical. Although tempting (and the subject of a large literature), such analogies should be carried out cautiously, as facile projections from one subject area to another are fraught with pitfalls. The argument that social phenomena or historical developments can be analyzed as analogous *to* biological processes is more misleading than helpful. Rather, my approach here is derived directly from the approach outlined in Aldrich et al. (2008), in which we argued that Darwinism in a historical framework is more of a general tool of analysis. The basic argument is not a facile shoehorning of complex social phenomena into a framework derived from biology but rather a *generalized Darwinism* that "relies on the claim of common abstract features in both the social and the biological world; it is essentially a contention of a degree of ontological communality, at a high level of abstraction and not at the level of detail" (Aldrich et al., p. 579).[8]

Before proceeding, it is important to distinguish between such terms as "culture" and "institutions." For my purposes it seems best to regard culture as something *entirely of the mind,* which can differ from individual to individual and is, to an extent, a matter of individual *choice.* Institutions are socially determined conditional incentives and consequences to actions. These incentives are parametrically given to every individual and are beyond their control. In that way institutions produce the incentive structure in a society. Institutions as "rules" can be seen as a special case:

[8] Many scholars have argued for more precise isomorphisms between natural and economic history. For instance, Vermeij (2004, p. 247) has argued that "human history recapitulates the much more protracted history of life as a whole."

the rules specify certain behaviors to be proper and legal, but they also specify the penalties for breaking them and the rewards for meeting them.[9] Beliefs and preferences are the "scaffolds," to use Douglass North's (2005) term, of institutions. In a sense culture forms the foundation of institutions, in that it provides them with legitimacy.[10] In a different context, Leighton and López (2013, pp. 11, 112–22) create a similar framework, in which incentives determine behavior, institutions "frame" incentives, ideas influence institutions (provided circumstances are favorable), and entrepreneurs make change happen. That is not to say, of course, that every institution is necessarily supported by a majority of the population; many institutions serve a small minority that uses its power to extract resources from others (Acemoglu and Robinson, 2012). Regarding beliefs as the foundation of institutions is oversimplified. Greif, in his attempt to define institutions with care, points out a problem with the "institutions-as-rules" idea, namely that without a meta-rule (or ethic) that rules should be respected and followed, rules and laws may well be empty and unenforced suggestions.[11] For him, institutions should be seen as a set of factors that generate regularities in behavior. By this definition, institutions however, inevitably contain in some measure beliefs as well, and thus would violate my attempt to keep them apart. To be sure, institutions in turn affect cultural beliefs in many ways and through many mechanisms (Alesina and Giuliano, 2016, pp. 6–7). Perhaps the best way of thinking of the relationship between the two concepts is to realize that they coevolve, much like a species and its environment. Recent research by economists and other social scientists has examined the details of this coevolution process in detail and concluded that it can easily lead to multiple equilibria outcomes, in which "good institutions" (defined as those that lead to better economic

[9] This is a variation on Bowles (2004, pp. 47–48) who defines institutions as "laws, informal rules, and conventions that give a durable structure to social interactions ... and make conformity a best response to virtually all members of the relevant groups."

[10] The mapping from one to the other is far from monotonic, however. The political process that converts beliefs into institutions is noisy and depends not only on beliefs but also on the ability of those who hold the beliefs to persuade or coerce others to accede to the institutions. As Szostak (2009, p. 234) notes, many institutions are little more than the "codification" of beliefs. Thus, an aversion of violence in a society may lead to formal legislation against it, and the conviction that wearing seatbelts in cars (a cultural belief) reduces accident fatalities leads to legislation making them mandatory (an institution). A cultural belief that the use of narcotics is bad may lead to an institution that mandates prison terms for drug use.

[11] As Greif (2006, p. 7) put it, rules "are nothing more than instructions that can be ignored. If prescriptive rules of behavior are to have an impact, individuals must be motivated to follow them. ... By 'motivation' I mean here incentives broadly defined to include expectations, beliefs, and internalized norms."

performance and growth) interact with a culture that enforces them, whereas bad institutions may reinforce a culture that perpetuates them.

Other scholars have used related if somewhat different definitions. Thus Roland (2004) suggests that culture as defined be included as a "slow-moving institution" that affects political and legal arrangements that can be changed faster; he prefers to limit the word "culture" to beliefs about the interaction of individuals, driven by social norms. Either way, however, there is a consensus that the incentive structure of society rests on a foundation of ideas, some of them about nature, some about human interactions, and still others of a moral nature. In other words, institutions rest on a bedrock of what people believe and know (or, to be more precise, *think* they know). If the culture and the institutions are misaligned, the foundations become unstable. If there is a clash between culture and institutions, in the sense that the underlying belief or legitimacy for certain institutions has eroded, a political disequilibrium has emerged. Unfortunately, there is no good theory to predict what happens then; in some cases the institutions are overthrown, but in others through political and military means, those who benefit from the institutional status quo can hold on to power and the resources that come with it for a long time.

If institutions have indeed become one of the main explanations of why some nations are economically successful—as the modern consensus increasingly seems to suggest—how do institutions relate to cultural beliefs?[12] At first glance the connection between culture and institutions seems tenuous. The institutional variation on our planet suggests that societies with similar cultural and environmental characteristics can have quite different institutional set-ups. The almost hackneyed example is of course Korea, where an arbitrary line dividing a single nation in two created two dramatically different societies. The different development in the past decade between Venezuela and Colombia could be cited as another example. Through sheer bad luck some countries ended up with predatory rulers or aggressive neighbors who created bad institutions that thwarted economic growth and caused a great deal of human misery. While such institutions have low legitimacy, they can survive by using a high level of coercion—which itself is a costly and inefficient way of maintaining bad institutions, thus compounding poverty and backwardness.

Culture, then, helps determine what kind of institutions emerge, but it does not guarantee outcomes. Indeed, one of the first and most influential papers in the analysis of the role of institutions in economic history (Greif, 1994) used the term "cultural beliefs" to identify the forces that underpin changes in institutions and thus to understand how they

[12] Acemoglu and Robinson (2012, pp. 56–63) dismiss the role of culture as an independent factor, and stress the importance of institutions without fully recognizing the possible effect of the dominant beliefs and values on the kind of institutions that emerge.

supported markets and exchange. Greif's point was that if the economic game is to have a cooperative equilibrium, what people actually believe about how others behave helps determine how they themselves will act in a variety of situations of interest to the economic historian. In short, if economists admit that economic history cannot do without institutions, it cannot do without a better understanding of culture. They like things, however, clear-cut, precise, and if possible formally modeled and testable. This is a daunting task.

Moreover, as already noted, causality does not run purely from culture to institutions. Institutions create the environment in which cultural evolution occurs. Much of what is to follow describes cultural changes as a result of the incentives and stimuli provided by an institutional environment. Institutional outcomes, moreover, have a large aleatory component. They are the result of battles, dynastic arrangements, power struggles, the arbitrary preferences of unusually influential or powerful individuals, political compromises, and maps drawn by generals or politicians. There was nothing inevitable in the survival of relatively tolerant institutions in the Low Countries and Britain in the seventeenth century, any more than in the emergence of very different institutional outcomes in Korea or Germany after World War II. Such differences often seem to be the outcome of historical flukes rather than of deep cultural processes. Furthermore, institutions, once in place, can display considerable durability and persistence even if they do not conform with the cultural beliefs of most people. As long as the interests of a few powerful groups are served, they can maintain a set of institutions for a very long time (Acemoglu and Robinson, 2006). It is hard to deny that importing such institutions as free-entry markets, fair and general-franchise elections, and freedom of speech and association into a society in which the Enlightenment culture that underpins them is not widely shared is at best an uphill struggle. Yet, perplexingly, it is not impossible.

As already noted, culture is shared, yet individuals will normally differ in some ways from one another in what they precisely believe, just as they differ in genotype. This analogy should also not be pushed too far; above all, cultural beliefs are not like genes in that the latter are "immutable for life." Above all, they are a matter of choice.[13] Individuals can make explicit choices to either accept the default cultural characteristics they were born with or to reject them and replace them with something else that they select from their cultural menu. Of course, we do not always know how

[13] To be sure, even in biology, modern research has blurred some of these sharp distinctions. While the inherited DNA sequence is immutable over a lifetime, cells can acquire and pass on to their progeny information acquired over their lives through epigenetic inheritance using methylated bases in the DNA. These do not alter the proteins but affect the chances of their being transcribed. See Jablonka and Lamb (2005, pp. 113–46).

and even when some preferences and beliefs are acquired, and shedding them may be difficult. However, it is not quite correct to compare preferences to accents (Bowles, 2004, p. 372), because accents for most people become fixed as teenagers, whereas a taste for certain forms of art or food can continue to evolve over a lifetime, even if the likelihood of change declines with age.

Some pathbreaking research on the economics of culture and how beliefs can affect economic performance has recently been carried out by theorists and empirical economists alike.[14] One mechanism through which culture is believed to have affected economic performance is through the idea that higher trust and cooperation reduce transaction costs and thus facilitate exchange and emergence of well-functioning markets. Another is civic-mindedness. A spirit of public consciousness and willingness to abstain from free-riding behavior in collective actions supports a higher supply of public goods and investment in infrastructure than is otherwise possible. The beliefs that makes such behavior possible depend crucially on the beliefs regarding the behavior of others; this is a classic example of frequency-dependence in the choice of beliefs, a topic I return to below in chapter 5.[15] The importance of these elements was already pointed out by John Stuart Mill ([1848], 1929, pp. 111–12) and different levels of trust have been shown to explain income differences between nations (Zak and Knack, 2001).

As noted, both theorists and applied economists have shown a growing interest in the economics of culture. Among the theoretical works by economists on the origins of culture are the pathbreaking papers by Bisin and Verdier (1998, 2011), which for the first time brought to economics the important work on cultural evolution done by scholars of cultural anthropology and population dynamics. The empirical work on the economics of culture depends heavily on data from the World Values Survey, Gallup World Poll, and similar data (Guiso, Sapienza, and Zingales, 2006; Tabellini, 2008, 2010; Deaton, 2011). This work has successfully addressed a whole set of issues of supreme importance to economists such as household behavior and female labor force participation, corruption, and migration (Fernández, 2011). It also draws heavily on experimental data, which suggest that culture modifies behavior in many ways that qualify and nuance the standard economic assumptions of individual utility maximization in such obvious set-ups as simple ulti-

[14] Much of this work is surveyed in Bisin and Verdier (2011) and Alesina and Giuliano (2016). It is striking that there seems to be very little work so far done on the cultural factors behind scientific and technological progress.

[15] In Greif's (1994, p. 915) terms, cultural beliefs are the expectations that individuals have about the actions that others will take. To that we should add the further belief that individuals hold regarding the morality of a particular action.

matum games (Bowles, 2004, pp. 110–19). A recent essay by Rodrik (2014, p. 189) complains that ideas are "strangely absent" from modern models of political econom—but the same might be said about models of economic growth and innovation, though recent work has made a beginning at coming to grips with the cultural roots of these phenomena (Spolaore and Wacziarg, 2013).

Most research by economists on culture as they see it focuses primarily on social attitudes, beliefs, and preferences supporting informal and formal institutions that increase cooperation, reciprocity, trust, and the efficient operation of the economy (Guiso, Sapienza, and Zingales, 2008; Bowles and Gintis, 2011). More recently, economists have become interested in attitudes toward discipline, education, work, time, self-control, and similar areas. Cultural beliefs also help determine, for instance, whether preferences might be "other-regarding" (that is, whether the consumption of others affects one's well-being) and whether they might be "process-regarding" (that is, whether the utility one derives from being in a particular state of the world depends on the way that state was reached rather than on the intrinsic quality of the state itself). Both of those types of preferences are not normally part of the analysis of economic preferences, but there is no inherent reason they should not be.[16] A good example of process-regarding preferences is when an individual cares whether he or she earns income by creating wealth through entrepreneurial activity or by redistributing it from others through rent-seeking or corruption. Does one regard a dollar in the same way no matter how it was earned, or does one care whether it was made while providing a socially useful activity? Is a dollar earned the same as a dollar stolen? Such preferences could make a difference in the institutions that are critical to the emergence of a civil economy and economic growth (Bowles, 2004, pp. 109–11; Bowles and Gintis, 2011, pp. 10–11, 32–35).

In what follows, I concentrate primarily on the one element in cultural beliefs that economists have so far neglected almost entirely, namely the attitude toward Nature and the willingness and ability to harness it to human material needs. Ultimately the relations with *makom*, or the physical world around us in the end determine the growth of useful knowledge and eventually that of technology-driven growth.[17] Technology is above all a consequence of human willingness to investigate, manipulate, and exploit natural phenomena and regularities, and given such willingness, the growth of the stock of knowledge that underpins and conditions the exploitation of knowledge. The willingness and ability to acquire, disseminate, and harness such knowledge are themselves part of culture and thus determine the intensity of the search for knowledge of nature, the agenda of the research, the institutions that govern the community doing the research, the methods of acquiring and vetting it, the conventions by which such knowledge is accepted as valid, and its dissemination to others who might make use of it. It is in this general area that the roots of modern economic growth should be sought—specifically in events and phenomena that precede the eighteenth-century Enlightenment and Industrial Revolution in the centuries that are known, for better or for worse, as "early modern Europe," roughly speaking between the first voyage to America by Columbus and the publication of the *Principia Mathematica* by Newton. It is the basic argument of this book that European culture and institutions were shaped in those centuries to become more conducive to the kind of activities that eventually led to the economic sea changes that created the modern economies.

[16] Many modern economists have, of course, seen the obvious connections here. Thus one has summarized that "what people believe what it takes to become prosperous has much to do with how they behave" (M. Porter, 2000).

[17] In her excellent and exhaustive surveys of the literature on culture and economics, Raquel Fernández (2008, 2011) does not deal much science or technology or indeed the accumulation of knowledge in any form, although she stresses that "The relationship between technology and culture also needs to be investigated" (2008, p. 10).

Chapter 2

Nature and Technology

I have already noted that there is an obvious limitation to the approach focusing on institutions to explain long-term economic growth. Such phenomena as trust, honesty, cooperativeness, thriftiness, public-spiritedness, and law-and-order can explain a great deal of economic performance: the emergence and growth of trade at arm's length, the evolution of nonpersonal credit networks, better land and labor markets, and thus more efficient resource allocations. But in the end, they cannot explain the miraculous explosion of science and technology in the past two and a half centuries that engendered modern economic growth.

At a high level of abstraction, the difference between "Smithian" and "Schumpeterian" growth is that for the former, exchange and cooperation based on trust or respect for the law are treated as a game between individuals whereas the essence of Schumpeterian growth is based on the manipulation of natural regularities and phenomena and thus au fond should be seen as a game against nature. However, only in the extreme limit is innovation a game against nature *alone*. There can be technological change in a Robinson Crusoe economy, but in any society, coming up with a technical solution to a problem is only the beginning of success. In practice, innovation requires a great deal of social interaction with creditors, workers, suppliers, customers, and the authorities, and all these relations involve elements that are part of a "civil economy." Society can set up institutions that reward innovators in a variety of ways—through patents, prizes, or patronage—or it can try to discourage them by, for instance, accusing them of "black magic." One particular aspect of culture that has been much discussed in recent years as a key to economic development is public sector corruption and the institutional environment in which innovation must operate. Vested interests of incumbents protecting the rents generated by status quo techniques and fear of the unknown and novel create strong incentives to resist innovation. If groups committed to these beliefs control the formal apparatus of the state, they can thwart

innovative efforts. Moreover, certain culturally determined preferences will have a positive spillover effect on technology, even if that was not their intention: investment in the human capital of children and a low rate of time preference and risk aversion come to mind.

Culture can thus affect technological creativity through institutions. But growth through innovation is in large part dependent on a direct link between culture and technology, through attitudes toward nature and the beliefs regarding relations between humans and their physical environment. The most direct link from culture and beliefs to technology runs through religion. If metaphysical beliefs are such that manipulating and controlling nature invoke a sense of fear or guilt, technological creativity will inevitably be limited in scope and extent. The legends of the ill-fated innovators Prometheus and Daedalus illustrate the deeply ambiguous relationship between the ancient Greeks' religious beliefs and their attitudes toward technology. If the culture is heavily infused with respect and worship of ancient wisdom so that any intellectual innovation is considered deviant and blasphemous, technological creativity will be similarly constrained. Irreverence is a key to progress. But so, as Lynn White (1978) has pointed out, is anthropocentrism. In his classic work, White stressed the importance of a belief in a creator who has designed a universe for the use of humans, who in exploiting nature would illustrate His wisdom and power.

As White and many authors have stressed, social attitudes toward production and work (and leisure) are another major factor in determining the likelihood of innovation. Technologically progressive societies were often relatively egalitarian ones. In societies dominated by a small, wealthy, but unproductive and exploitative elite, the low social prestige of productive activity meant that creativity and innovation would be directed toward an agenda of interest to the elite. The educated and sophisticated elite focused on efforts supporting its power such as military prowess and administration, or on such topics of leisure as literature, games, the arts, and philosophy, and not so much on the mundane problems of the farmer in his field, the sailor on his ship, or the artisan in his workshop. The agenda of the leisurely elite was of great importance to the lovers of music in the eighteenth-century Habsburg lands, but was not of much interest to their farmers and manufacturers. The Austrian Empire created Haydn and Mozart, but no Industrial Revolution. As McCloskey (2006) has stressed, the bourgeois societies of the Netherlands and Britain of the seventeenth century, in contrast, were prime candidates for technological advances. Technological progress might take place in areas that interfaced with the military or with civil administration, such as the advances that the Romans scored in hydraulic and construction engineering, but agriculture and manufacturing made little progress during the heyday of the Roman Empire.

A somewhat different link between potential technological creativity and underlying cultural values has to do with individualist vs. collectivist cultural norm (Gorodnichenko and Roland, 2011; see also Triandis, 1995). Gorodnichenko and Roland define a variable they dub "individualism" which measures the degree that societies reward such personal accomplishments as innovations. Placing low values on individualism means that collective actions are easier to achieve, but it flattens the reward structures and thus discourages individuals from standing out. Hence individualism stimulates innovation by not penalizing heterodox intellectuals who come up with unconventional and possibly heretical ideas and think outside the box (Triandis, 1995). The cultural beliefs underpinning the institutions that set these incentives are a good example of how such cultural beliefs can influence innovation, but they concern how society should operate, not the relation between individuals and their environment. Societies and nations differ in their valuations of such cultural norms, and it seems plausible that more individualist cultural norms will be more consistent with technological progress—if indeed the institutions they undergird encourage technological creativity and not more destructive forms of individualism such as military prowess. Gorodnichenko and Roland argue plausibly that in fairly poor societies collectivist values may lead to more productivity growth but that for truly original innovations, individualist values are more important. While their data are for a cross-section of modern countries and show an unambiguous relation between their measure of individualism and economic outcomes, there is not much evidence to indicate that historically individualism played a similar role.[1]

A related and important literature focuses on the distinction between *general* and *specialized* (or limited) morality (Tabellini, 2008, 2010). In a specialized morality society, individuals care primarily about themselves and members of their immediate environment (say, close relatives and friends) and much less about the larger society in which they live, so that they tend to be more opportunistic when they deal with unknown persons. A general morality means one also cares about people one does not know. Innovation, because its benefits affect a larger community (and possibly humanity at large), is at least in part more likely to occur in a society that has opted for a more general morality, in which innovators are motivated by a desire to do something for a large number of people, or at least acquire the respect of others who care about such things. Especially because in the production of useful knowledge nearly all the economic surplus thus created accrues to consumers (that is, anonymous people), general morality encourages more research that has no direct and immediate payoffs to the creator than specialized or "local" morality.

[1] MacFarlane (1978) has argued explicitly that late Medieval England was very much an individualist society and drawn a link between that individualism and eighteenth-century industrialization.

That said, culture can affect technological progress in many ways other than metaphysical beliefs and individualism, and they will be at the center of this book. Cultures can be backward- or forward-looking in the sense that some may hold the knowledge and learning of previous generations in such high esteem that novel ideas run a serious risk of being viewed as apostasy. At the other extreme, cultures can regard everything new as an improvement, so that only the newest beliefs and gadgets are held in high regard. Religions, with some notable exceptions, have tended toward conservatism in this regard. For most of its post-temple history, Judaism was, on the whole, committed to the unchallenged authority of the writings of previous generations, and new ideas had to be camouflaged as commentary and exegesis of ancient texts. In Christianity, physics and metaphysics often collided, and as a result the revolutionary theories of Copernicus and Darwin, in very different eras, ran into serious resistance from people with strong religious beliefs. Scientific and technological innovation, of most interest to economic historians, often ran and still runs into resistance in backward-looking cultures, in large part because every invention is an act of rebellion against time-honored beliefs and deeply entrenched customs.

A critical cultural belief that drives economic growth and complements the belief in the "virtuousness of technology" is a belief in progress, and specifically in economic progress. Such a belief has positive, normative, and prescriptive components. First the positive component means the acceptance of the belief that material progress is *possible*, that is, history shows an upward trend and not just stationary cyclical movements and this trend can be continued. It opposes the "Ecclesiastes view of history," which stipulates that long-term change is impossible, because "there is nothing new under the sun." A belief in future progress, of course, requires an implicit model of what could have brought about such progress as well as evidence that such progress had happened in the past. As I argue in detail in chapter 14, such a model and the evidence supporting it emerged in seventeenth-century Europe and became a major force in the age of Enlightenment. The model postulates that what contemporaries called "useful knowledge" (roughly speaking, science and technology) could become an engine of economic progress through improving production techniques.

Second, the normative component postulates that economic progress is *desirable*, eschewing any notions that the accumulation of wealth and material goods is somehow sinful or vain. Such beliefs are a good illustration of the kind of dilemma faced by economists trying to think about culture. Were the beliefs that wealth accumulation was sinful— embodied in the famous New Testament statement that it was unlikely for a rich man to enter heaven and Plato's belief that the more riches and rich men are honored in the state, the more virtue and the virtuous are dishonored—

simply a rationalization of the inevitable poverty that a static technology and extractive institutions imposed on economies incapable of growth? Or were they in part an autonomous cultural force that was itself a cause of poverty by guiding the motives and incentives of the best and brightest members of society toward activities that were not conducive to economic growth? A similarly Weberian distinction can be made about whether intellectual activities were mystical and other worldly, with an attitude of resignation toward the environment, or directed toward the world, practical and materialist, believing that virtue and salvation were to be attained by confronting and achieving control over natural forces and using those resources for the good? Whatever the case, what is crucial is to see how that circle was broken in Europe and eventually led to the Industrial Revolution and the beginnings of modern growth (McCloskey, 2006, 2016a).

Third, once the possibility and desirability of economic progress had been accepted, a concrete *agenda* of policy measures and institutional change had to be formulated, elaborated, proposed, and implemented for long-term progress to take place. This agenda became increasingly concrete and detailed in the eighteenth century and was implemented, in different ways, in some European nations the late eighteenth century and then more widely in the nineteenth century. There was, of course, no unique way of carrying out this agenda. In some countries the "policies" were largely based on private initiative and spontaneous organization. In others the state needed to play a proactive role. Whatever the exact agenda, the policies had unintended consequences. At least in that regard they were like all evolutionary processes: messy and imprecise, full of false starts and dead ends.

These three cultural elements have roots that go far back into early European history, certainly to the late Middle Ages and possibly before. But before 1750 they did not produce anything like an Industrial Revolution or sustainable economic growth propelled by technological progress. Although held by a few individuals in earlier times, such attitudes were not sufficiently widespread to make a difference. The emergence of such beliefs among some individuals is never sufficient to generate economic growth; they must emerge in the right environment—one that is somehow conducive to rapid changes in attitudes and beliefs, which ultimately affect every aspect of society. The key element here is that those who propose the new ideas must have the opportunity to persuade others. Cultural change is to a large extent about *persuasion*. What makes persuasion possible—though not inevitable— is a technology for discourse and communication that is sufficient to reach the audience that matters, and the establishment of rhetorical rules sufficient to convince them (McCloskey, 1985, pp. 27–28). Another critical element is that entrenched conservative elements trying to resist intellectual innovation for some reason are weakened. Finally, we would expect to observe the proliferation of new ideas in societies where there is some compelling reason to doubt the traditional wisdom as inconsistent with indisputable new facts that have come to light in recent years. Such an anomaly between beliefs and facts could occur, for instance, when two societies that were hitherto unconnected establish contact, so that they learn about each other. The environment described is a fair (if schematic and oversimplified) description of Europe in the two centuries after 1500.

Chapter 3

Cultural Evolution and Economics

In this chapter I use an evolutionary approach to culture.[1] As already noted, it can be extremely misleading to "shoehorn" the methodology of one field into another. Economics in particular and the social sciences in general are decidedly not like biology. Looking for forced parallels and analogies is not a useful strategy. But using the parallels that do exist and pointing out the differences can be illuminating.

Evolutionary models have had a mixed record in economics; despite the influence of Nelson and Winter's (1982) seminal book, mainstream economics has typically relegated evolutionary models to niches, such as evolutionary game theory. An attempt to use gene-culture coevolution to explain the emergence of successful cooperation in human societies can be found in Bowles and Gintis (2011). In economic history, except for a few attempts to use evolutionary models of technology, these ideas have had little impact.[2] Their introduction into economic history, at first blush the research area most amenable to evolutionary models, has been slow. Recently, Darwinian models of selection have been proposed to explain the economic transformation of Western Europe and the emergence of modern growth (Galor and Moav, 2002; Clark, 2007). Such models mark a considerable advance in applying Darwinian models to economic growth. The idea in this literature is that the agents who are most likely to perform well in the economy and thus to be agents of economic growth also tend to have differential reproduction rates, so their share in the population keeps rising. The cultural traits these agents embody might be called "middle class values." They emphasize investment in human

[1] For a recent summary of this literature, see Mesoudi (2011) and Richerson and Christiansen (2013).

[2] See for instance Constant, 1980; Vincenti, 1990; Ziman, 2000.

capital, industriousness, thrift, and other elements of what is sometimes misleadingly thought of as "the Protestant ethic." As Deirdre McCloskey (2006) has stressed the bourgeois ethic involves an implicit recognition of the value of progress: hard work and education can make one better off, and thus collectively and cumulatively generate a trend of progress. A rise in the prevalence and social prestige of such "bourgeois values" would be a powerful factor in explaining economic performance. But can such a rise be better understood with Darwinian models? The rigid evolutionary approach, while different from the one used here, employs the important assumption that culture is essentially hereditary and thus passed on from parent to child. This somewhat restrictive assumption permits the possibility of using models of Darwinian selection. The basic idea is that differential reproduction, working mostly through the larger number of surviving "high-quality" children, leads to an expansion of middle class culture and thus eventually to successful economic growth.

There is a great deal of validity in these arguments, even though it would take many centuries for a relatively small group even with significantly higher reproduction rates to become a majority in the population.[3] The agents who constitute the engine of technological progress are usually a fairly small proportion of the population, the right tail of the human capital distribution. Beyond the great inventors, the Industrial Revolution required a larger cadre of mechanics, highly skilled artisans, entrepreneurs, financiers, merchants, and organizers of different kinds. But the world of useful inventions remained to be conquered what Robert Hooke called "a Cortesian army, well-Disciplined and regulated, though their numbers be but small" (cited in Hunter, 1989, p. 233). The Industrial Revolution did not require, or cause, the transformation of an entire economy or labor force, and evolutionary models that depend on the numerical growth of this key group through differential reproduction are missing the boat. In mechanical Darwinian models, culture is assumed to be set for life at conception; there is little room in these models for learning, persuasion, or imitation.

The more plausible way to use evolutionary models in economic growth is to take the "cultural element" to be the unit of selection rather than its carrier. That gets rid of the knotty problem of selection on humans, which generates slow cultural change because of the long length of a

[3] One constraint on the success of Darwinian models in the preindustrial West is the institutional constraint of monogamy, which placed limits on the most successful males to propagate their genes (unlike, say, the Yanomanö Indians documented by Napoleon Chagnon, where the most aggressive males were allowed to have more wives). Leaving out their undeniable potential to have illegitimate offspring (who were, however, severely handicapped in most Western societies), the only way in which more successful individuals could have a reproductive advantage in these societies is through lower infant mortality, which has been documented for small samples in seventeenth-century Britain but seems a relatively weak quantitative reed to lean on.

human generation. The cultural elements themselves, and not their carriers, are subject to evolutionary forces. It is important not to push the analogy too far, looking for particulate and discrete units such as "memes" that would be isomorphic to genes and even might be "selfish" like them. Evolutionary models are larger than Richard Dawkins, even larger than Charles Darwin (Hodgson and Knudsen, 2010). Above all, they involve selection, but the selection here is not the natural selection that occurs through population dynamics but the conscious choices made by individuals.

Every person forms a unique cultural phenotype much like every person forms a unique biological genotype, but how is this phenotype formed? Cultural evolution sees this as essentially a quasi-Lamarckian process, in which individuals acquire cultural characteristics through learning and imitation during their lifetimes and pass these on to others. They choose their cultural elements (or stick to the default, which are the beliefs and preferences they acquire from their parents during socialization). It does not rule out a genetic component in the choices made.[4]

Darwin was the first to point out in his *Descent of Man* that culture exhibited certain evolutionary characteristics.[5] Three elements make these frameworks Darwinian, as much of this extensive literature has noted (Aldrich et al., 2008, p. 583). One is that cultures, much like species, contain a great variation of traits, the results of past innovation. Many of these traits are shared among certain groups of individuals and distinguish them from those belonging to other groups. Yet the lines are often blurry, as they are between species, and cultural overlaps are common. Jews and Muslims share a belief in a single God and a taboo on the eating of pork, yet they are distinct groups in a way not dissimilar from two species that share the vast bulk of their genes and yet are phenotypically quite distinct.

The second is that culture, much like genes, is passed on among individuals, either vertically from generation to generation or horizontally among separate units. Genetic transmission occurs through mitosis in eukaryotic cells, cultural transmission through socialization and learning in

[4] Recent work by James Fowler and others indicates that ideology and other cultural variants may have a genetic component, working through dopamine receptor genes that are inherited (Fowler and Schreiber, 2008).

[5] Darwin made this point especially poignantly with respect to language, one of the main components of any culture. See Darwin (1859/1871, p. 466). The classic works in the mid-1980s by Cavalli-Sforza and Feldman (1981) and Boyd and Richerson (1985) both stress the evolutionary features of culture. Recent research in anthropology and social sciences has shown that evolutionary approaches can indeed be quite fruitful if still controversy-ridden (Henrich, Boyd and Richerson, 2008; Hodgson and Knudsen, 2010; Mesoudi, 2011). These approaches have also become a cornerstone of a certain line of cultural argument associated with Richard Dawkins and his followers, who have tried to identify units of cultural analysis equivalent to genes.

cultural processes. Children are being socialized by parents, but socialization (that is, the vertical transmissions of information from parents to children) is not all there is to choice-based cultural evolution; children are socialized by other children and non-parents, and as adults they can still be subject to persuasion and other forms of cultural ontogeny and engage in choice-based learning albeit at a declining rate with age.[6]

The third is that there are "too many" cultural features so that individuals have to choose among menus. In biology, what drives evolution is superfecundity: species have the capability to reproduce at a rate much faster than is needed for replacement, which means that not all those who can be born will be, or that those born will actually survive. This is the Darwinian "struggle for existence." Natural selection is driven by a process in which those with the most fit features have a better chance to survive and reproduce. Cultural features are "superfecund" in that there are far too many of them produced for an individual to absorb, so that selection must take place among sometimes enormous menus. There are 10,000 distinct religions in the world, and 6,800 different languages. No individual can believe in all religions and speak all languages. One has to choose. The same is true, say, for a belief about the causes of business cycles: does one believe they are primarily generated by real productivity shocks or by financial-sector shocks? In many other cases, however, new information is piled on top of old, and by accepting the new as valid, one does not necessarily have to make a choice. In this regard the superfecundity feature of the evolutionary model is a constraint that is not invariably binding.

These three characteristics—variation, inheritability, and superfecundity—as Darwin showed, are sufficient to ensure that selection is adaptive: when there is a change in the environment, cultural traits trend to change through the retention of some and the elimination of other elements. The exact unit of this selection is the "cultural element" that remains at the center of the debate (Mesoudi, 2011). The cultural evolution literature has argued that cultural evolution does not require the much stricter conditions imposed on evolution after Darwin by the neo-Darwinian synthesis. These additional conditions postulated further constraints on evolution: the so-called Weismann barrier (acquired phenotypical characteristics are not passed on to following generations); the random ("blind") occurrence of mutations (so that *all* direction in evolution is imparted by selection); and the particulate nature of transmission by discrete units

[6] Social values may be part of the changing life cycle, as illustrated by the famous quote attributed to Winston Churchill but actually first stated by the French historian François Guizot that if you are not a left-leaning liberal when you are 20 you have no heart but if you're not a conservative at age 40, you have no brain, implying that people become more conservative with age. As argued by Tuschman (2014), personalities may be hard wired for shifts over the life cycle and changes in gene expression may alter openness to new ideas, conscientiousness, and other traits.

(genes) (Mesoudi, 2011, pp. 40–47). Darwin had a theory of evolution without knowing about the neo-Darwinian synthesis, and while the latter has worked miracles in making the theory of evolution a coherent biological doctrine, Mesoudi makes a persuasive case that these principles are not needed for an evolutionary theory of culture. Where the use of biology is unnecessarily confining, it should simply be abandoned. Evolution occurs on cultural variants, which are neither random mutations on existing variants nor necessarily slow cumulative variations that are retained selectively. The discrete units (memes) are purely imaginary and not all that useful. Above all, learned characteristics can be passed on—indeed, this is the very engine of cultural change. Of the various aspects of cultural change, what is of central interest here is changes in useful knowledge, leading ultimately to changes in technology and economic welfare.

The odd thing is that when otherwise insightful cultural evolutionists come to the history of technology, they seem to fall into the same errors they warn against in almost the same sentence. Thus, after they dismiss the idea of sudden and discrete leaps in genotypes leading to major differences in phenotypes, they mechanically extend the notion of gradualism to the history of invention. The history of technology, Richerson and Boyd (2005, p. 51) assert, depended on "complex artifacts ... built up piecemeal by the cumulative improvements of technologies at the hands of many innovators ... each contributing a small improvement to the ultimately amazing instrument" (see also Mesoudi, 2011, p. 33 for a similar view). It is far from obvious on what evidence this extension of evolutionary gradualism to the history of technology is based. To say that *every* technique embodies some previous technological component (as does Basalla, 1988) is no more a refutation of saltationism than to point out that even Goldsmith's hopeful (and possibly fanciful) monsters and the rapidly changing species in Gould's and Eldredge's punctuated equilibria involved pre-existing DNA. In fact, few examples are more striking than the one ironically deployed by Richerson and Boyd (Harrison's H-4 marine chronometer) and Mesoudi (Newcomen's steam engine) to show that discrete leaps in technology did in fact take place. The history of technology is, in fact, full of major discontinuities in which novel designs created totally new options. From time to time, one can observe a "hopeful monstrosity—indeed no better one than Thomas Newcomen's Dudley Castle engine, installed in 1712.[7] More broadly, it is easy to spot discontinuous leaps in culture. Each of them inevitably contains elements of earlier features, but they are phenotypically and functionally sufficiently different from what came before to qualify as hopeful monsters. None of this refutes the point

[7] The term "hopeful monstrosity" was coined by the evolutionary biologist Richard Goldsmith (1940) in his now largely discredited view that evolution could at times advance by discrete quantum leaps in which altogether new species emerged quite suddenly.

that for every successful radically new design, there are far more that languished largely forgotten on inventors' workbenches. Consider the Stirling engine, invented in 1816, or funicular railroads.

To be sure, most technological progress and productivity growth are very much the result of the slow and gradual accumulation of small changes. Saltationism does not deny that. However, such small changes—or microinventions as I have elsewhere called them (Mokyr, 1990)—tend to run into diminishing returns after a while. What is needed for sustained innovation is the injection of a new idea, or at least an idea from a very different area, what Matt Ridley (2014) has called in a memorable phrase "ideas having sex." Improve a horse and buggy all you will, it will never become a bicycle; improve a bicycle all you will, it will never become a Segway. The statement that even such novel designs contained some existing components detracts nothing from the revolutionary nature of the new design.[8] More to the point, perhaps, is that fundamentalist incrementalism as proposed by George Basalla and others overlooks the complex interplay between prescriptive knowledge (technology) and the propositional knowledge that underpins it (its epistemic base). The positive feedback between those two can create rapid, even explosive, advances that clearly refute any loose analogies to evolutionary gradualism (Mokyr, 2002). Hopeful monsters who catch on for one reason or another are not only to be found in technology. The history of culture is full of rather sudden discontinuities that may appear inevitable and obvious ex post but were hard to predict ex ante, from Newton's *Principia* to Beethoven's *Eroica* to Darwin's *Origins*. Whatever the origins of these successful "monsters," they led to discontinuous changes.

There are many caveats to borrowing concepts from evolutionary biology for understanding of cultural change. It is far from obvious, for instance, what exactly is meant by the biological concepts of species and speciation in cultural models, since if species are defined by reproductive isolation, they have no meaning in a cultural context. The same is true for the concept of a "generation" in cultural evolution. Intergenerational information in neo-Darwinian models is transmitted only during mitosis, although by now it is quite clear that certain bacteria can actually acquire genetic information from other entities through such mechanisms as transduction. Cultural evolution places no upper bound on the number of sources of culture. Furthermore, there is no reason to believe that innovations occur wholly at random, much like mutations. In biology we do not get more mutations of a particular kind just because we need them. In culture the relation between innovations and perceived needs may be noisy,

[8] In Mokyr (1991), I provide five examples of such macroinventions during the Industrial Revolution: gaslighting, the breast wheel, the Jacquard loom, chlorine bleaching, and hot-air ballooning.

but a correlation seems plausible. Those who create the innovations do not exert their efforts at random, and while often they discover unexpected novelties, and innovations have many unintended and accidental consequences, these point to a noisy but not a wholly random process. For instance, a large literature in the economics of technological progress points to a search for labor-saving innovations in economies that have expensive workers, and while this literature has been heavily criticized, it is still true that one would expect inventors to work on issues that they deem for one reason or another to be a socially high priority, whether finding a smallpox vaccine or developing a nuclear bomb.

What, then, is actually gained from an evolutionary approach to culture? As explained in Aldrich et al. (2008, p. 589), such an approach supplies a framework for explaining the evolution of complex, undesigned outcomes over time, and it involves both the adaptation of cultural beliefs to changing circumstances and the elimination of others through selection. Economists still committed to the Popperian notion that science has to make some kind of falsifiable predictions will find little of use here. For the economic historian, the great advantage of evolutionary thinking is that it tries to explain why the present is the way it is and not some other way by using history. It encourages us to look at how the past shaped the present using Darwinian concepts, above all the concepts of choice and selection, and how such choices are made from past choices and innovations. Evolutionary thinking does not provide a clean and ready-made methodology like standard economics, but for a historical analysis of intellectual innovation, it has certain merits. Below I list some of the main advantages of an evolutionary approach to the history of culture.[9]

First, evolutionary systems are characterized by a fundamental duality of information and action, of genotype and phenotype. Distinctions between genotype and phenotype are hazardous to extend to cultural history, but all the same something can be learned from them. Culture is about matters of the mind; behavior and actions are the observable outcomes of preferences and knowledge (Mesoudi et al., 2013). But, as already noted, the mapping from beliefs to behavior is no simpler than that from genes to phenotypes; at best there are loose statistical associations masking the interactions of many variables.[10] One reason is that beliefs, much like other genotypical processes, affect "adjacent" beliefs. We can indeed speak of cultural *pleiotropy*, much like in evolutionary processes. Pleiotropy means

[9] For a similar argument, with a slightly different emphasis, see Mesoudi et al (2013).

[10] A good example can once again be found in the history of technology. In Mokyr (2002), I distinguish between propositional and prescriptive knowledge, the former roughly corresponding to a genotype, the latter to an observable technique. There is no easy mapping between the two. Sometimes techniques are used with virtually no understanding of why and how they work. At other times, the necessary underlying knowledge may well be there, but the techniques fail to emerge. Moreover, there is no clear-cut causal arrow between them; the best

that a certain genotypic change leads to more than one phenotypical effect, because of the spillover effects on genes in the proximity of the mutation, in a sort of genetic packaging. A parallel phenomenon is *epistasis,* in which more than one piece of information is required to jointly bring about a certain trait or behavior. Such bundling often occurs in cultural evolution: a growth in the belief in the virtue of commercial activity may be associated with a growth in the belief in the value of useful knowledge although there is no necessary association.

Second, evolution is about the interaction between a pre-existing environment (in which an innovation is introduced) and the innovation itself. Innovation, as noted, remains a stochastic variable, even if it is in some sense directed and not purely random (as mutations are supposed to be in a pure Weismannian world). We do not know precisely why a certain idea occurs to an individual at a particular time, and why in some societies certain ideas simply never occur at all. The likelihood of an idea occurring to anyone is affected by the environment and perceived needs. But even if the flow of innovations were wholly predictable, we would not be able to predict with any certainty their success unless we could measure their "fitness" relative to the environment in which they take place, which determines whether they will catch on. What makes matters even more complicated is that even if it were possible somehow to predict the likelihood of an innovation succeeding in a given environment, that success is likely to produce complicated feedback effects because it is likely to change the environment itself.

Third, evolutionary systems are based on the dynamics produced by superfecundity and selection. The system throws up more variants than it can possibly accommodate, and so some form of winnowing must take place. The notion of natural selection in biology is purely metaphorical. Nobody actually makes choices, and the selection mechanism is wholly driven by differential reproduction and survival. In contrast, people actually make conscious choices choosing one cultural element over another from a menu of options, and then display the behavior implied by this choice. Like species, some ideas may go "extinct" in the face of a powerful new competitor (for example, geocentric astronomy or miasma theories of disease) but in other cases new ideas may coexist with the old ones in some kind of mixed equilibrium in which the competitive environment is insufficiently stringent to bring about a complete domination of the innovation. As I shall argue below in chapter 5, this can happen when knowledge is *untight*, that is, not very certain and not easily verifiable by the rhetorical criteria of the time. The idea of a niche is appropriate here: some environments provide an opportunity for minority cultural beliefs to survive and sustain themselves—one thinks of the Amish, flat-earthers, or Trotskyites.

Fourth, evolutionary models are rich: they allow change to occur on different levels. There is a long debate whether this occurs in biological systems and what the appropriate unit of selection is. Some biologists, led by George Williams and Richard Dawkins, feel that all selection happens at the level of the gene and nowhere else, but others strongly argue for selection at the level of the cell, the organism, the species, or even populations. Whatever the outcome of this literature, it seems beyond question that in cultural evolution selection can happen at many levels. To see this, consider a novel cultural trait offered to an individual in a particular society. If the individual chooses the variant and not another, this is one level of selection at which choice-based cultural evolution occurs. Now assume, however, that this variant increases the fitness of the individual and thus extends his life expectancy and/or the number of surviving children who resemble him. This increases the chances that the trait will be passed on, either vertically through the socialization of offspring or horizontally through "infecting" his immediate neighbors. Furthermore, suppose that society as a whole has now adopted the trait, and that it increases the fitness of the group (for example, through more cooperation or adopting a superior technique); this may mean a higher population growth rate in a society that has adopted the trait, and thus it is likely to increase its relative frequency in the global population. Evolution is not a single process, but a complex and intertwined system of conscious choices and "natural selection" at different levels.

Fifth, like all evolutionary systems, culture is resistant to change. In the technical language of evolutionary dynamics, prevalent cultural variants are evolutionarily stable strategies with respect to most conceivable innovations ("mutants"). There are built-in mechanisms that maintain a certain stability and provide an advantage to incumbent cultural variants against innovations, but the effectiveness of these mechanisms is itself a function of the content of the system. Ernst Mayr (1989, p. 35) has suggested that genes "perform as teams" and that "epistatic interactions form a powerful constraint on the response of the genotype to selection." Cultural elements, too, form a coherent system, which may resist change because of the interdependence of its components (Bateson, 1979, pp. 176–80).[11] For instance, a complex religious culture in which some elements are out of tune with perceived reality may either adapt to reflect new beliefs or cling to increasingly antiquated beliefs. The power structure within the organizations that depend on these beliefs (as is the case with the Catholic church today) may either dig in and fiercely resist change or adapt. In cultural systems (with no obvious parallel in biology), culture is tied up with what we could call cultural capital, investments that people have made in the current beliefs that would decline in value if the current beliefs were to be modified or overthrown. Physicists resisted quantum mechanics, physicians the germ theory, and chemists the atomic theory for precisely such reasons. No matter what kind of cultural system we are looking at, there will be some resistance to change, and many seemingly "fit" innovations will fail in a hostile environment biased toward conservatism.[12] In other cases "cultural species" can coexist for long periods indeed. The "new science" that emerged in the sixteenth and seventeenth centuries did not replace the Aristotelian orthodoxy in a few years or decades, but shared the same environment, at times as substitutes but often in some kind of harmony or compromise that may seem implausible to us now.

Sixth, an evolutionary framework implies that any easy generalizations or predictions about the speed and direction of cultural change are doomed. Most of the time culture changes at a tectonic pace, surviving dramatic institutional and political shocks. But at times culture changes quickly as a result of weakened resistance, perhaps, or some powerful exogenous shock that challenges existing cultural beliefs deeply (Jones, 2006). Much like evolutionary science, the strength of the methodology is that it helps us make sense of the past rather than predict the future. Precisely because the unit of analysis continuously interacts strongly with its environment and because there are few time-invariant relations, it becomes unpredictable (Saviotti, 1996, p. 31). Moreover, as John Ziman (2000, p. 50) has pointed out, selectionist models stress that often what matters is not statistical averages over large numbers of similar states or agents, but rare events that are amplified and ultimately determine outcomes.[13] The challenge to historians then becomes to try to understand which rare events take on that function, and under what circumstances they are "selected." In principle, of course, there is no reason to presume that evolutionary models should be confined to finitely lived beings endowed with a genotype derived from one or two parents, subject to differential reproduction. In other words, thinking in evolutionary terms boils down to what Mayr (1982, pp. 46–47) sees as the main power of evolutionary models: what he called "population thinking." This idea stresses the importance of individual variation within populations and its ability to bring about changes in the many starting from the few. If we are interested in

11 The idea of inertia and resistance to radical change is common to all evolutionary systems (see Cohen and Stewart, 1994, pp. 92ff, 332), who define a concept of "canalization." See also for example Mayr (1991, pp. 160–61) who uses the term "cohesion."

12 Recently, economists (Benabou, Ticchi, andVindigni, 2014) have developed models to formalize the problem, pointing out that certain kinds of innovations reduce the value of existing ideas by being "belief-eroding," even if that was not their original intent. This creates an obvious conflict between those whose beliefs are being threatened and society at large, which stands to benefit from such ideas because they increase economic performance.

13 This has long been realized by evolutionary biologists, who have postulated that major evolutionary advances come from unusual and exceptional genotypes with opportunities to dominate their own small populations and radiate into marginal habitats. See Stebbins (1969, p. 142).

economic change at the macro level, such population thinking is critical. Much economic change is brought about by the few affecting the many.

Finally, an evolutionary approach gives us a more reasonable way of thinking about how and why historical trajectories were followed. It places the analysis between the extremes of a materialist analysis that regards historical outcomes as inexorable and foreordained and a nihilist approach that sees nothing but randomness everywhere. The Great Divergence and the Industrial Revolution that caused it were neither fluke nor necessity, to paraphrase Jacques Monod's (1971) famous title. Nor were the Scientific Revolution or the Enlightenment.[14] They arose because historical circumstances were conducive to the sprouting of seeds that were already present in the soil. Evolutionary innovation occurs because a mutation takes place that happens in an environment favorable to it. But such a mutation is a minute subset of all favorable mutations that might have happened, as well as the smaller set of all mutations that actually did happen but turned out to be unviable. Evolutionary theory reminds the historian that contingency is everywhere: not everything that happened had to happen, and that many things that could have happened did not. It also reminds us that similar circumstances do not always lead to the same outcomes and that similar outcomes do not always have identical causes. The language of evolution suggests the distinction between homologies (similar outcomes resulting from similar origins) as opposed to analogies or homoplasies (similar outcomes with different origins). The work by economists on the interaction between culture and institutions reinforces this interpretation by recognizing that these models have multiple equilibria and that societies may start from similar circumstances and yet end up in very different situations "depending on historical idiosyncrasies" (Alesina and Giuliano, 2016, p. 44). In both approaches, a guiding principle is that nothing was inevitable about the actual historical outcomes we observe. And yet, it seems plausible to argue that even if developments on different parts of the globe were never quite independent, they still can yield insights about some role for historical regularities and causation; not everything is accidental in history. As Vermeij (2004, p. 250) remarks, comparative history helps us separate chance and necessity. Hence it is important to compare the experience of Europe with that of another culture, for example China (see chapters 16 and 17).

14 For a powerful statement in the same vein about the Scientific Revolution, see Cohen (2012, p. 204). He argues that the emergence of a "realist-mathematical" (that is, modern) science was always a possibility, but its realization was not foreordained—we might still be living in a world in which Archimedes and Ptolemy represented the summit of scientific achievement and the astrolabe and mechanical clock the supreme examples of toolmaking, with "death within a year of birth as the likeliest human fate by far."

Furthermore, evolutionary systems have been argued to generate a general trend toward progress, at least in the sense of growing complexity and diversity. While the matter is still quite controversial, one eminent biologist has pleaded with his colleagues to adopt a view in which this trend in history is a central organizing principle. "History, then, is not random change. Among competitive dominants, there is a trend toward increased power through time ... a trend toward increased diversity of membership and increased productivity" (Vermeij, 2004, p. 252). Others are much more skeptical (for example, Futuyma, 1986, p. 366). As we shall see in chapter 14, concepts of a discernable trend in history became part of the culture of the period between 1500 and 1700. If we see the history of culture and that of living species as instances of a generalized Darwinian system, a discourse on the plausibility of some kind of trend that can be viewed as progress is apposite.

Episodes of scientific and technological flourishing have occurred throughout history, but the one that occurred in Europe after 1700 was in many ways unique. It was not the ineluctable culmination of Western history, nor a sign of the greater dynamism of Western culture, but the unintended and unanticipated result of a set of circumstances that affected the culture of some parts of Europe and through them the institutions that set the parameters of intellectual development. Neither the classical world, nor the medieval church, nor the Renaissance made the material successes of the West inevitable (Goldstone, 2012). Indeed we can view the economic developments of the past two centuries much as we view the emergence of *Homo sapiens* in the past half million years, after sixty-five million years of mammal evolution in which species came and went, but none had the fortune of developing the central nervous system that changed the world (Vermeij, 2004). It could have happened at another point in time, and it could easily not have happened at all or been nipped in the bud at an early stage. The story of evolution is, by and large, the story of species that survived—at least for a while.

The literature of cultural evolution is largely concerned with the emergence of tools in ancient societies. Imitation and learning-by-doing are the mechanisms of change. In such a world technological progress will be slow because "it is typically more difficult to make large improvements by trial and error than small ones" (Boyd, Richerson and Henrich, 2013, p. 135). But when cultural evolution began to involve *persuasion* regarding the natural principles that make techniques work, the game of innovation was changed forever, and increasingly discrete leaps in technology became increasingly frequent. That, in the end, is the tale underlying the Great Enrichment.

Chapter 15

The Enlightenment and Economic Change

The market for ideas and the cultural entrepreneurs of the seventeenth century who emerged from it gave rise to the intellectual movement known as the Enlightenment: a complex, heterogeneous, and at times mutually incompatible set of cultural beliefs, but all the same a cultural sea change that uniquely marked Europe to become the locus of economic modernity. For the economist asking questions about the roots of European economic development, however, consistent themes in the elite culture all point in the same direction: a culture of practical improvement, a belief in social progress, and the recognition that useful knowledge was the key to their realization. These beliefs were complemented by other cultural elements we see as enlightened: the idea of political power as a social contract, formal limits on the executive branch, freedom of expression, intellectual contestability, religious tolerance, basic human legal rights, the realization that exchange was a positive-sum game, the virtuousness of economic activity and trade, the sanctity of property rights, and the folly of mercantilist notions that placed the state (and not the individual) as the ultimate object of society.

The increased prevalence of these beliefs, which fit uneasily but conveniently under the big umbrella of the Enlightenment, was the cultural underpinning of economic growth, the scaffold on which new and more prosperous economic buildings could be erected. Of all those beliefs, the notions about the power of useful knowledge to transform the economy constituted the driving force in bringing about the Great Enrichment. Economic growth could take place (and still does) in economies in which human rights are trampled on, with little freedom of expression or equality before the law, in which property rights are enforced only for the rich and powerful and in which government is tyrannical and corrupt. What counts for economic history was the beginning of a long and drawn-out rise in the belief in the transformative powers, social prestige, and virtuousness of useful knowledge.

Without the continuous emergence of new techniques based on a better understanding of natural processes, growth will inexorably grind to a halt.[1]

The central messages of the Enlightenment that mattered to subsequent economic change were products of the competition in the market for ideas and were a direct continuation of the Republic of Letters. The economic dimensions of the European Enlightenment, discussed in Mokyr (2002, 2009a), are sufficiently important to merit special monikers, such as the "Industrial," the "Medical" Enlightenment, and the "Commercial" Enlightenment.[2] The impact of the cultural change was decisive, especially in Britain, in which a scientist (Newton) and later an engineer (Watt) became symbols of a national spirit and a heroism that had nothing to do with the battlefield and everything to do with the creation of useful knowledge. In most other European societies, such prestige was still associated with other activities, primarily military or artistic, but over time the British example and influence led to the dissemination of these beliefs throughout most of the Continent. In the North American colonies and the United States, the odd mixture of Puritan values with elements of the French and Scottish Enlightenment were decisive in setting the culture of the young republic in the 1780s.

The strength of the ideology of progress in the eighteenth century was in its hope, not its realization. Indeed, the technological experience of the age of the early Industrial Revolution shows the Baconian program to be a disappointment (Mokyr, 2009a, p. 59). Yet even in those early decades of modern economic growth, the cultural changes in the sphere of useful knowledge interacted with the world of production through many channels and the two reinforced each other. In some sense, the statement that economic progress was affected by technological change is so obvious as to be almost trivial, but the insight has been clouded by the somewhat dated dispute on the role of science in the Industrial Revolution.[3] As economic historians have known for many years, it is difficult to argue that the Scientific Revolution of the seventeenth century we associate with Galileo, Descartes, Boyle, Newton, and others had a direct and major impact on the pivotal technological breakthroughs of the eighteenth-century Industrial Revolution,

[1] One reflective modern scientist, wondering about the long-term evolution of knowledge, has argued that pessimism has been an endemic part of every society, "with the single, tremendous exception (so far) of the Enlightenment" (Deutsch, 2011, p. 216).

[2] The concept of a Medical Enlightenment was first proposed by Roy Porter (1982) and refers specifically to the belief that growing useful knowledge could and would reduce the incidence of disease. The concept of an Agricultural Enlightenment was first proposed in Mokyr (2009a, pp. 171, 186); see also Jones (2016). The concept of a Commercial Enlightenment is proposed by Abbattista (2016).

[3] The *opus classicus* arguing for a key role for science in the Industrial Revolution remains Musson and Robinson (1969). For the best, more recent, statement arguing for the importance of science see Jacob (1997, 1998, 2014) and Jacob and Stewart (2004). For arguments to the contrary, see Hall (1974), Mathias (1979), and Landes (1969).

especially in the key sectors of textiles and iron. Technological progress in the Industrial Revolution, most students are taught, was the result of inspired tinkering by brilliant and dexterous craftsmen with no more than a smattering of best-practice science (which was not very good to start with).[4] Many modern historians see it the same way. As Charles Gillispie (1980, p. 336) has remarked, in the eighteenth century, whatever the interplay between science and production may have been, "it did not consist in the application of up-to-date theory to techniques for growing and making things."[5] More recently, Roberts and Shaffer (2007, pp. xxi– xxii) have stressed the importance of a "practical intelligence" or what they choose to call "cunning" (meaning dexterity and intuition) as a source of innovation and point out that it could easily combine with science. And yet, dexterity and practical intelligence by themselves would have run into diminishing returns; whether it was soap boiling, hydraulics, or fireworks making, in the end economic history confirms Bacon's statement that by themselves "neither the bare hand nor the unaided intellect has much power" adding that "human knowledge and human power come to the same thing because ignorance of cause frustrates effects" (Bacon, [1620] 2000, p. 33 aphorisms ii and iii). Had skilled artisans and dexterous workers by themselves been able to make more than local and marginal changes in technology, the Industrial Revolution might have taken place in India.

On the eve of the Industrial Revolution, it was not easy to see the fruits of science translated into practical uses. In 1704, one of Jonathan Swift's protagonist ancients makes the devastating remark that "if one may judge of the great genius or inventions of the *Moderns* by what they have produced, you will hardly have countenance to bear you out" (Swift, [1704] 1753, pp. 185–86). Half a century later, Dr. Johnson, writing an essay titled "What Have You Done?" in *The Idler* in December 1759, expressed the disappointment of the age: "When the Philosophers of the last age were first congregated into the Royal Society, great expectations were raised of the sudden progress of useful arts; the time was supposed to be near when

[4] Voltaire ([1733--34] 2007, p. 39) felt that the most useful inventions are not "those that do the most honor to the human mind" and that "we owe all the arts [technology] to mechanical instinct and not to orthodox philosophy."

[5] John R. Harris, one of the leading historians of the technology of the Industrial Revolution, has been even more skeptical of the importance of science relative to the "tacit" skills that he regarded as crucial to technological advances in the eighteenth century. He has even argued that France's backwardness in steelmaking was in part due to its reliance on scientists, who at first gave misleading and later rather useless advice to steel makers. See Harris (1998, pp. 219–21). For a powerful recent statement doubting the role of scientific progress in the technological advances of this period, see McCloskey (2010, ch. 38) who denies that "high-brow science" made much of a difference before the late nineteenth century, which still leaves a lot of room for low-brow science, from Watt's friend and advisor Joseph Black to Eugène Chevreul, the French chemist (whose scientific understanding of fatty acids made important improvements to the manufacture of soap and candles).

engines should turn by a perpetual motion, and health be secured by the universal medicine; when learning should be facilitated by a real character, and commerce extended by ships which could reach their ports in defiance of the tempest. But improvement is naturally slow. The society met and parted without any visible diminution of the miseries of life. The [gout] and [stone] were still painful, the ground that was not ploughed brought no harvest. ... The truth is, that little had been done compared with what fame had been suffered to promise; and the question ["what have you done?"] could only be answered by general apologies and by new hopes, which, when they were frustrated, gave a new occasion to the same vexatious enquiry" (Johnson, 1759). Steam power, perhaps the most spectacular technological offspring of the scientific breakthroughs of the seventeenth century, was as yet an exciting but economically marginal technique.

To be sure, a few important inventions, even before 1800, can be directly attributed to scientific discoveries or were dependent in some way on scientific insights. Yet the bulk of the most significant advances in physics, chemistry, biology, botany and other areas occurred too late to have an effect on the great changes of the last third of the eighteenth century we associate with the Industrial Revolution. Crucial as they were to the understanding of the universe and the evolution of nineteenth- century technology, they were largely peripheral to the main thrust of the eighteenth-century Industrial Revolution. Yet this was not for lack of trying. During the age of Enlightenment, and especially the decades after 1750, much of Europe witnessed a flourishing of interest in the application of useful knowledge to the arts and crafts as well as to agriculture. The important thing about the culture of useful knowledge in Europe, however, was not that it yielded immediate economic benefits, but that most practitioners believed that in the very long run it would. Bacon's vision was to be realized, but it became a matter of centuries, not decades.

Moreover, there were exceptions, and these were important, less in their direct economic impact (though it was there in a few cases) than in demonstrating the potential of the Baconian promise. As already noted earlier, Newcomen's atmospheric engine required some notions that had been developed by experimental philosophers, above all the realization of atmospheric pressure and that a vacuum was possible and could be exploited (Wootton, 2015, pp. 500–8). This is not to suggest by any means that the concepts of energy were well understood: the well-worn adage that science owed more to the steam engine than the steam engine owed science is certainly apt. Yet it still is undeniable that without the work of a long line of well-trained natural philosophers beginning with that of the Neapolitan Giambattista della Porta via the discovery of the atmosphere by Torricelli in 1643 and all the way to Denis Papin, who built the first workable model of an atmospheric engine in the 1690s, it is hard to see Newcomen's device succeeding (Kerker, 1961; Cohen 2012, pp. 476–78, 729; Wootton, 2015, pp. 490–95). Advances in the chemical industry, such as the soda-making process

and chlorine bleaching came relatively later (1780s) and were based on a very partial understanding of the chemistry involved. Yet again: without any input from scientifically trained chemists such as Scheele and Berthollet, it may be doubted that chlorine bleaching would have evolved when it did (Musson and Robinson, 1969, pp. 251–337). Wootton (2015, p. 489) remarks that early modern science solved two of the most difficult problems it set for itself: the calculation of the trajectory of a projectile, and the determination of longitude at sea. I would add to that a third: the means of preventing smallpox, first through inoculation, and later by vaccination.

Much depended on the capabilities of eighteenth-century science and mathematics to come to grips with difficult problems of energy, materials, and biology. When it could be done, however, it was successful. Consider the work of a relatively obscure figure of the Industrial Enlightenment, Benjamin Robins (1707–1751). Robins was a self-taught mathematician, who renounced his Quaker background to apply best-practice mathematics and physics to engineering and then to ballistics. In the words of his biographer, "his *New Principles of Gunnery* [1742] transformed ballistics into a Newtonian science" (Steele, 2012). His work was quite influential, winning him the Copley Medal, and translated into many languages (into German by none other than Leonhard Euler who was working on similar problems). His ideas were widely implemented and led to military reforms in the Austrian and French artillery.[6] An example of a vexing practical problem that the advances in both propositional and prescriptive knowledge between 1500 and 1700 helped solve was the measurement of longitude at sea. The issue had been on the forefront of natural philosophy, and some of the greatest minds had worked tirelessly to solve it using new insights in astronomy and the new tools that had become available. Galileo, for one, hoped to use his discovery of the moons of Jupiter in determining longitude. The invention of the spiral-spring balance in watches by two of the best minds in the seventeenth-century, Huygens and Hooke, was another contribution to this effort. Without the insights of propositional knowledge, Harrison's marine chronometer (completed in 1759) would never have been made. None of this argument detracts from the contribution of the brilliant clockmaker. It points to the basic fact that skills and theory cooperated and complemented one another in making the Industrial Revolution possible.

Another successful application of increased scientific understanding to a directly useful purpose was the growth of gas lighting in the late eighteenth century (Tomory, 2012). The scientific basis for the controlled burning of gases was pneumatic chemistry, a branch of science that went back to van

6 Steele (1994) sees Robins's work as an example that "contradicts the perception that rational mechanics had little effect on early modern mechanical technology" (p. 380) and that "The ballistics revolution . . . contradicts the popular idea that the experimental and mathematical sciences remained essentially separate until the 19th century" (p. 381).

Helmont in the early seventeenth century. It was taken further by giants of the Industrial Enlightenment such as Joseph Black, Antoine Lavoisier, and especially Alessandro Volta. New scientific instruments and a growing need for lighting public areas and factories produced a major multinational effort in the use of gas lighting in the closing decades of the eighteenth century. As Tomory notes, the actual industrial process developed turned out to be an accidental by-product of distillation of hydrocarbons. But as so often was the case, the role of science was captured by Pasteur's famous dictum that Fortune favors prepared minds (and, one might add, prepared minds coupled to dexterous hands). In many ways, gas lighting is a perfect illustration of the economic impact of the Industrial Enlightenment, and not just in a literal sense. It was based on a combination of imperfect but experiment-based scientific understanding and artisanal brilliance; it was geared toward the solution of a recognized practical need; it was multinational in nature and very much an outcome of open science.

The same can be said about hydraulics, another area where theory and practice came together in the kind of fashion that the Baconians had dreamed about a century earlier. Here the pioneering figure was the French mathematician Antoine Parent (1666–1716), a somewhat underappreciated polymath, who published an influential paper on the efficiency of water wheels (1704) that soon became the standard text on hydraulics. Parent had applied the newly-invented differential calculus to find the maximum efficiency of water wheels, and it became a cornerstone of one of the first major engineering handbooks published, B. F. de Bélidor's *Architecture Hydraulique* (1737–1753). Parent's findings were adopted by eminent mathematicians, such as d'Alembert and Leonhard Euler (Reynolds, 1983, p. 207). Yet his work also serves as a good illustration of the highly erratic and non-linear trajectory of the much-touted collaboration of theory and practice, as it contained a number of errors first pointed out by Daniel Bernoulli in the 1730s. It took many more decades to straighten out the theoretical basis of water power, and the pathbreaking work on hydraulics by the French mathematician Jean-Charles de Borda (1733–1799) remained unrecognized for many years.[7] Yet the eighteenth-century Republic of Letters never wavered in its belief that such a basis would eventually be attained, and that an understanding of hydraulics would serve to build more efficient machines. That belief was Bacon's legacy and it was a consensus that the age of Enlightenment inherited from the market for ideas of the centuries before 1700.

[7] David Wootton remarks that the case of water wheels is especially interesting because hydraulic technology had developed very slowly for a thousand years and yet the efficiency of water power took off in the age of Enlightenment. Wootton (2015, pp. 486–89) attributes this advance to the experimental methods as embodied in the work of John Smeaton, but the theoretical work of (mostly French) physicists complemented these experiments.

How essential was formal scientific knowledge to the emergence of modern growth? Could high-skilled artisans by themselves have brought about the Industrial Revolution? Hilaire-Pérez (2007) and Berg (2007) have argued that an artisanal "economy of imitation" could have led to a self-sustaining process of improvement. Artisans by themselves normally reproduced existing technology, and in that process at times an incremental micro-inventive sequence led to significant improvements, but in the end these advances were limited.[8] The institutional arrangements of the artisanal economy (mostly the craft guilds) helped diffuse techniques spatially, but Epstein's (2013, p. 67) view that regards them as inherently dynamic and progress oriented—and that the acceleration of technical innovation in the eighteenth century was more likely to have been caused by "technicians" than by an intellectually driven Industrial Enlightenment—is not persuasive. It was not one *or* the other: useful knowledge and artisanal dexterity were strongly complementary, and they created a synergy that changed the history of humankind, precisely as Bacon had hoped for. Had technological progress remained entirely unconnected to what happened at a higher intellectual level, had it consisted purely of disseminating and incrementally improving best-practice existing artisanal procedures, standardizing them, and hoping for learning-by-doing effects, the process would eventually have run into diminishing returns and fizzled out. A counterfactual world of technological progress entirely carried by skilled and imaginative artisans, without any input from Baconian-minded intellectuals and natural philosophers, might have seen some local technical advances in textiles and metals in the eighteenth century, but it would not have produced a sustainable and self-reinforcing Industrial Revolution. Many societies we associate with technological stasis were full of highly skilled artisans, not least of all Southern and Eastern Asia.

Without artisanal skill, however, the insights of natural philosophers would have had no economic impact. Artisans were an indispensable element in the progress of technology and a complement to radical inventions. They were the ones who carried out designs to specification, scaled up models, and materialized blueprints into new industrial equipment and materials. They installed and debugged complex mechanisms, made them work, fixed delicate machinery when it broke, and in general provided the tacit knowledge sometimes referred to obscurely as "skill" or "dexterity." But without the infusion of radical new ideas from natural philosophy, and eventually chemistry and mathematics, such capabilities would not have amounted to the "phase transition" that they became.

[8] Francis Bacon, who was an early believer in the value of artisanal knowledge, all the same complained that artisans confined themselves to the matters that pertained to the immediate tasks at hand, did not trouble themselves with more general issues, and would not raise their minds or stretch out their hands for anything else (Bacon, [1620] 1999, p. 130, aphorism 99).

Hilaire-Pérez (2007) emphasizes the innovative capacity of French artisans in their guilds, and the examples she cites are interesting. There can be no doubt that in a purely artisanal world, evolutionary sequences of microinventions did take place that led to considerable technological progress, both product and process innovation. Moreover, some of the more interesting "great inventors" of the age—starting with Newcomen and his assistant John Calley, the clockmaker John Harrison and the instrument maker James Watt—were skilled artisans themselves. Yet artisans, unless they were as unusually gifted and well educated as the brilliant inventor Jacques de Vaucanson (1709–1782) or the ingenious French armorer and inventor Edme Régnier (1751–1825), were good at making incremental improvements to existing processes, not in expanding the epistemic base of the techniques they used or applying state-of-the-art scientific knowledge to their craft. In other words, a purely artisanal knowledge society will not create a cluster of macroinventions that revolutionized production from the foundation.[9] Artisans were also not well positioned to rely on the two processes of analogy and recombination, in which technology improves by adopting or imitating tricks and gimmicks from other, unrelated, activities. If all that were needed for the Industrial Revolution had been enlightened and ingenious artisans, it could have occurred centuries earlier. Skilled artisans, after all, had been around for centuries, and could be found in India, the Middle East, and China. Focusing on artisans alone makes it difficult to understand why things moved so rapidly after 1750 and continued to do so after 1820. In textiles, the technical problems were on the whole less complex than in the chemical industry or in power engineering, but even there some help from mechanical science found its way to the shopfloor with important consequences for productivity and efficiency (Jacob, 2007).

When all is said and done, the technological revolutions that brought the world economic growth and prosperity were not the result of either artisanal ingenuity or scientific method and discovery, but from the confluence of the two. That confluence is the essence of the Industrial Enlightenment. It saw in the successful application of useful knowledge (including, but not confined to, Newtonian science) the empirical validation of the principles it tried to discover, but its science depended on the tools that technology supplied and the agenda that production difficulties and human needs provided. Enlightenment mathematicians, such as Euler and Borda, worked on ways to make water wheels more efficient. Natural historians, such as René Réaumur, looked for ways to understand insects and prevent their damage to farming, and the great naturalist the Comte de Buffon (1707–1788) studied

[9] Watt knew this all too well and sought contact with the best natural philosophers he could find in his milieu, especially the Scottish scientists Joseph Black and John Robison. Less well known is his reliance on the discovery of another Scottish scientist, William Cullen, that within a vacuum the boiling temperature of water is much reduced, which inspired his insight of the separate condenser.

the mechanical properties of wood used in naval construction. Benjamin Franklin and Franz Aepinus, among many others, struggled to try to understand electrical phenomena. It was understood by Enlightenment thinkers that the marriage between science and production could yield enormous benefits to humankind. But the courtship was to last for centuries.

What is it that natural philosophy brought to the table in the decades during and following the burst of macroinventions we identify with the classic Industrial Revolution? And why is the role of science so controversial? In part, it is our own way of thinking of "science" that is at fault, since we tend to think of science as more analytical than descriptive. The eighteenth century, however, spent an enormous amount of intellectual energy on describing what it could not understand. The three "Cs"—counting, classifying, cataloging—were typical of the Baconian program that the seventeenth century bequeathed to those who came after them. In that sense Carl Linnaeus and the versatile and productive Swiss physician and botanist Albrecht von Haller (1708–1777) were perhaps the more obvious carriers of the Baconian program than the Newtonians, as was Jean Jacques d'Ortous de Mairan (1678–1771) in France and Hans Sloane in England.[10] Organizing such knowledge in accessible ways, it was felt, would make it more intelligible and potentially more useful. The chemist Étienne François Geoffroy who claimed to have been inspired by Newton, wrote a famous paper that provided the first tabular arrangement of chemical substances according to their ability to dissolve another substance. It emphasized not the understanding of chemical facts but the ordering of the "brute phenomena themselves," as Dear (2006, p. 42) put it. It was devoid of any attempt to speculate on the reason why materials displayed different solubilities. Botany and zoology were treated in the same way: by cataloging and classifying, it was hoped, some patterns and regularities would emerge. In the absence of a clear concept of evolution, to say nothing of more advanced physiological concepts, many skeptics such as Buffon thought such a project foolhardy. Yet Linnaeus and his many disciples persisted in what became a central project of Enlightenment science. Linnaeus, as a physician, was above all interested in the materia medica. But he went beyond that: his belief that skillful naturalists could help transform farming was widely shared, and it inspired the establishment of agricultural societies and farm improvement organizations throughout Europe. By the second half of the eighteenth century, botany, horticulture, and agronomy were working hand-in-hand through publictions, meetings, and model gardens to introduce new crops, adjust crop

[10] Sloane's defense of a purely empirical science was that "the Knowledge of Natural History, being Observations of Matters of Fact, is more certain than most others and ... less subject to Mistakes than Reasoning, Hypotheses and Deductions are ... these are things we are sure of so far as our senses are not fallible and have been ever since creation" (Sloane, 1707, vol. I, unpaginated preface). Mairan was the founder of chronobiology and discovered among others the existence of circadian rhythms in plants.

rotations, and improve tools and farm management.[11] The empirical work of naturalists, such as Linnaeus, and eighteenth-century agricultural experts, such as Arthur Young and John Sinclair, were very widely read, if perhaps rarely with direct results on agricultural productivity. But there is no question that these scientists had recast their role in human society. As Koerner (1999, p. 11) observes about Linnaeus and his students, they "understood the dynamic of history to be the interplay of *natura* and *patria*, and how they (Enlightenment improvers to a man) cast *themselves* as agents of historical change" (emphasis in original). The Baconian origins of this attitude seem beyond question.

Beyond that, however, the role of natural philosophy in the intellectual evolution of the Enlightenment is more subtle than the rather simplistic search for the scientific origins of cotton-spinning equipment. The distinction between natural philosophers and "men of letters" was not nearly as sharp as the distinction between scientists and humanists is today. Montesquieu and Rousseau both had scientific training; Voltaire was a scientific amateur; and Adam Smith, Turgot, and Condorcet all had knowledge of astronomy and physics. As a result, scientific ideas and methods penetrated other intellectual discourses, and scientific terminology entered the debates on institutional reforms (Wuthnow, 1989, p. 174).

The Industrial Enlightenment, then, should be understood as a primarily empirical project, with only occasional flashes of analytical insight before the nineteenth century. Yet the collection and analysis of data was obviously of help in many practical applications. The search for empirical regularities in the data, to use a modern term, inspired Edward Jenner to see why some people seemed immune to smallpox. In animal breeding, in which British farmers scored significant advances, empirics was all they had to go by in the absence of any theory of evolution, let alone genetics. In metallurgy and engineering, the individuals doing the inventing on the ground (such as Henry Cort and Richard Trevithick) consulted empirical scientists, such as Joseph Black and Davies Giddy (Gilbert).

In short, the cultural beliefs that had been slowly ripening in the sixteenth and seventeenth centuries affected technology and eventually output, productivity, and economic performance, even if sometimes through roundabout mechanisms. One might legitimately ask whether the causality was not reversed. Culture might have been malleable and endogenous to the economy, as historical materialism would suggest. Even Merton, who was suspicious of historical materialism, felt that the Puritans' belief in progress was "a profession of faith which stemmed from their growing social and

[11] One source of confirmation of the belief in the possibility of economic progress may have been perceptions of agricultural progress. As John Gascoigne has noted, "as the land bore more, better, and increasingly diversified fruits as a consequence of patient experiment with new techniques and crops, so, too, the need to apply comparable methods to other areas of the economy and society came to seem more insistent" (Gascoigne, 1994 p. 185).

economic importance" (Merton, [1938] 2001, p. 81). The difficulty with choice-based cultural evolution is that at the end of the day, it is hard to know why some people are persuaded by certain novel beliefs and values and why others cling loyally to those of their parents or more generally to the ruling orthodoxy. Not all cultural choices were based solely on economic interest. At times, materialist arguments based on a *cui bono* logic can be shown to be demonstrably false, and enlightened thought at times defeated naked greed. Consider the debates in Britain around the abolition of the slave trade (1807) and slavery in the colonies (1833). Both of these were decisions in which a certain set of ideological persuasions defeated economic interests. It is telling that some leaders of the antislavery movement in Britain were enlightened industrialists, such as Josiah Wedgwood and his partner Thomas Bentley and the ironmonger Richard Reynolds.[12]

Yet the timing suggests, however tentatively, that the causality ran primarily from cultural change to the growth of useful knowledge, and not the reverse. At the time that Bacon was persuading (posthumously) men like Hartlib and Boyle about the control of nature, the idea that technological change could actually become a rising economic tide that lifted all boats still seemed far-fetched. Major technological breakthroughs, albeit important, had been rare and few in between, and there was little evidence that they made a significant difference in terms of economic growth. All the same, as noted, there had been successes in the late Middle Ages, including the introduction of the printing press, gunpowder, and the great voyages made possible by better charts, the compass, and improved ship design, and clearly these fostered a belief in human ability to control nature. But the role of systematic research in the creation of those advances had been small, and Bacon knew it (Gaukroger, 2001, p. 81).

Even Adam Smith, it is often remarked, did not realize that innovation was about to become an important (and eventually the central) source of economic growth. While he believed that Britain had been experiencing economic expansion in the centuries before, he did not foresee that useful knowledge would become the overwhelmingly powerful force it became. The hope of enlightened men and women in the early eighteenth century that useful knowledge would become the central factor in economic change was based not so much on experience and historical facts as much as on a metaphysical belief that the universe was knowable and manipulable, and the hope that the accumulation of natural knowledge would eventually pay off. Small advances bolstered this belief. In 1780 Benjamin Franklin wrote to his friend Joseph Priestley that "the rapid progress true Science now makes, occasions my regretting sometimes that I was born so soon. It is impossible

[12] James Watt, too, expressed his view that "the system of slavery (is) so disgraceful to humanity" which he hoped would be "abolished by prudent though progressive measures" and other members of the Lunar society mostly agreed (Dick, n.d., p. 10).

to imagine the Height to which may be carried, in a thousand years, the Power of Man over Matter. ... O, that Moral Science were in as fair a way of Improvement" (Franklin, [1780] 1840, p. 418). Priestley felt the same way, but it is hard to believe that the views of these two men who epitomized the Industrial Enlightenment in the English-speaking world were as yet commonplace in this era.[13] Some salient events may have helped to create a bias in this direction. Two of the most spectacular inventions of the eighteenth century, the steam engine and the hot air balloon, may have had that effect despite their marginal economic importance in the eighteenth century because of their visually awe-inspiring and revolutionary nature. Those inventions set imaginations racing, reinforced the belief in the human ability to understand and manipulate nature in ways never imagined before, and reinforced the hope that similar advances could be made in other fields, such as agriculture and medicine—hopes that were largely disappointed in the medium run and led to a great deal of frustration.

Moreover, the victory of the belief in technological progress as a benevolent and progressive phenomenon over the forces of resistance and inertia was far from a done deal even during the Industrial Revolution. There was considerable doubt about the desirability of technological progress. In the age of mercantilism, which was receding slowly but was still very much in force by the early nineteenth century, it was believed above all that employment and jobs were a central responsibility of ecnomic policy and thus often felt ambivalent about labor-saving technological progress because it was feared that such advances might lead to unemployment (Berg, 1980). Even David Ricardo, one of the great prophets of liberal political economy, expressed a deep concern that technological progress could throw workers out of work and that the "discovery and use of machinery may be attended with a diminution of gross produce; and whenever this is the case, it will be injurious to the labouring class as some of their number will be thrown out of employment" (Ricardo, [1821] 1971, p. 382). Resistance to technological progress, for a variety of reasons, has survived until the present. It has multiple roots, some of them purely material, other ideological (Bauer, 1995; Mokyr, 2009a, ch. 6).

The Industrial Enlightenment was a movement explicitly committed to the diffusion and dissemination of knowledge and ideas, that is, to exposing people to larger menus of cultural variants from which they could make informed and hopefully rational cultural choices. Here the rhetoric, the way people persuade one another, was central. The Enlightenment benefited from earlier changes in how novel cultural elements were evaluated before

13 Priestley wrote in 1771 that "All things (and particularly whatever depends on science) have of late years been in a quicker progress toward perfection than ever ... in spite of all the fetters we can lay upon the human mind... knowledge of all kinds ... will increase. The wisdom of one generation will ever be the folly of the next" (Priestley, 1771, pp. 253, 562).

they were accepted or rejected, that is to say, what forms content bias took. In this regard the progression from the seventeenth century Scientific Revolution seems natural. The rebellion against the authority of ancient scriptures and sages was continued by tightening the standards of evidence, making them more rigorous. What counted as persuasive evidence and proof itself underwent a process of cultural change: experimental methods were made more explicit and precise, and higher accuracy and more precise measurement became the rule.[14] The more reliable and accurate instruments were a key part of the persuasion process. For instance, the progress made in the understanding of heat transfer in the late eighteenth century owed much to improved thermometers (Heilbron, 2003b).

The Enlightenment invented the concept of *data*: an increasing number of scientific and technological works included a great deal of tabular material, examining, testing, and comparing (Headrick, 2000). In the second half of the eighteenth century, those in charge of augmenting the set of propositional knowledge and convincing others of the correctness of their innovations increasingly relied on quantification and formal mathematical methods (Frängsmyr, Heilbron, and Rider, 1990). The increasing reliance on mathematics and graphical representation in technical works supported this need for precise and effective communication. As Rider puts it, "mathematics was eminently rational in eighteenth-century eyes, its symbols and results were truly international ... in an age that prized the rational and the universal, mathematics ... offered inspiration and example to the reformers of language" (Rider, 1990, p. 115). Formal methods and quantification were an efficient language for communicating facts and relationships, and its rules are more or less universal (at least within the community that counted for the processing and application of useful knowledge). Computation and formal methods were necessary because they were an efficient way of persuasion and helped increase the tightness of knowledge: what was known became more certain, even if in many areas scientific disputes and bogus theories blossomed like never before. Theories lent themselves more readily to falsification and thus the knowledge generated by science became tighter.

Through meticulous procedures and sophisticated equipment, a rhetoric of precision emerged that facilitated scientific consensuses, if not always in straightforward manner.[15] Heilbron (1990, p. 9) submits that in the seven

14 An early example of this is provided by van Helmont. A supporter of the iatrochemical school started by Paracelsus, he challenged his Galenist opponents to take out 200 or 500 patients from hospitals and elsewhere, divide them into two equal groups, and then randomly assign one group to his treatment and the other to theirs, and submit them to the different treatments "and we shall see how many funerals both of us shall have" (Debus, 2002, p. 377).

15 The triumph of Lavoisier's chemistry over its British opponents in the later 1790s is a good example. Golinsky (1995) shows how his methods of quantification and precision helped persuade some skeptics (or in some cases failed to do so), but either way, precision and

teenth century most of "learned Europe" was still largely innumerate, but that in the second half of the eighteenth century propositional knowledge, from temperature and rainfall tables, to agricultural inputs and yields, the hardness and softness of materials, and economic and demographic information, was increasingly presented in tables. Readers were expected to be comfortable with that language or at least be willing to learn.[16] Tables not only made the presentation of information more efficient, they also organized and analyzed it by forcing the author to taxonomize the data. A booklet such as John Smeaton's famous *Treaty on Water and Wind Mills* used tables lavishly to report his experiments.

An important way in which the age of Enlightenment built on the Republic of Letters and improved the market for ideas was by organizing and formalizing the institutions of science. The seventeenth-century Republic of Letters was at first almost entirely virtual and had few formal organizations before 1660, the unofficial founding of the Royal Society. Renaissance academies such as the famous Accademia della Lincei were often virtual organizations.[17] Many informal, mostly short-lived, academies preceded the founding of formal academies after 1660. In addition to the Hartlib and Cavendish circles already mentioned, there were a number of groups of intellectuals organized by some leading figure such as the scholarly salon known as the *Cabinet des Frères Dupuy* organized by the learned bibliophile brothers Pierre Dupuy (1581–1652) and his brother Jacques (1591–1656). Among others, it was attended by Peiresc (who later maintained a detailed correspondence with the salon). It was a place in which letters and news from all of Europe converged and were discussed on a daily basis (Delatour, 2005a, p. 291). Its other regulars included the exiled Dutch jurist Hugo Grotius and leading French scientists of the age such as Pierre Gassendi and Marin Mersenne (Delatour, 2005b, p. 295). Another focus of the Republic of Letters in Paris was the group around Pierre Michon Bourdelot in the 1640s. The so-called *Académie Bourdelot* was a biweekly meeting in Paris attended by nobles, people of letters, philosophers, and people interested in science, and

measurement became an integral part of scientific discourse in the eighteenth century.

16 Scattered but persuasive evidence suggests that formal and precise methods filtered down to some parts of the production sphere and were applied to mundane purposes. An example is the work of the Irish-born mathematician and land surveyor John Dougharty (1677–1755), who wrote a widely used book on quantitative methods in gauging areas and volumes, replete with ready-to-use tables. The work was first published in 1707 and went through six editions until 1750 (Dougharty, 1750). While the work was dedicated to the commissioners and officers of the excise tax and composed for the "edification of young officers," it was clearly aimed at a much wider audience.

17 The Lincei academy did not meet often and did not have formal memberships or a brick-and-mortar center, except the palace of its patron, Duke Federico Cesi; it did give its members a sense of common purpose and the right to place a picture of a lynx on the title page of their books (Heilbron, 2003a, pp. 2–3).

it continued meeting until a year before Bourdelot's death in 1685. Among the attendees were the mathematician Gilles de Roberval (1602–1675), Gassendi, and Pascal. A bit earlier the circle around Marin Mersenne, known as the *Academia Parisiensis*, emerged, in which French and foreign intellectuals met to discuss science and mathematics (it was there that Blaise Pascal first met Descartes).

Outside France, one of the first academies of scholars was the *Accademia degli Incogniti* in Venice, founded in 1630 by intellectuals inspired by the teachings of Cesare Cremonini (1550–1631), a popular and heterodox University of Padua philosopher and close friend of Galileo's (Muir, 2007). The *Accademia del Cimento,* founded in 1657, was the private venture of Prince Leopold of Tuscany; it was mostly a group of Galileo's students and followers. It consisted of little more than a handful of notable experimental scientists such as Giovanni Alphonso Borelli and Vincenzo Viviani meeting in Florence under the auspices of the prince. Much like the earlier *Lincei*, it did not outlast its patron. In Germany, the first academy was founded in Schweinfurt in Franconia by a small group of medical doctors, and was named the *Academia Naturae Curiosorum,* later known as Leopoldina when it was officially sponsored by Emperor Leopold I in 1687. In the best traditions of the Republic of Letters, it claimed its objective to be the exploration of nature for the glory of God and the good of mankind. It had no permanent location, and worked mostly by correspondence but it published a scientific journal.[18] In that sense it was an intermediate form between the earlier spontaneous epistolary networks and the brick-and-mortar academies that emerged later. In England, Gresham College in London was established in 1598 under the will of Thomas Gresham, with the purpose of bringing together skilled artisans and scholars outside the universities, and its lectures were given in both Latin and English.[19] In the seventeenth century it became closely affiliated with the groups that later formed the Royal Society, which met at its premises before the great fire of London in 1666.

As Hunter (1989) notes, what brought about the formalization of these gatherings was a combination of the influence of Bacon's *New Atlantis* with its detailed depiction of a scientific academy, and a general movement toward more formalized and enduring forms of organization of all social activities in England culminating in the founding of the Royal Society in 1660. That change, however, hardly explains the almost simultaneous founding of the *Académie Royale des Sciences* in 1666 (and the *Académie de Peinture*

18 The journal was the *Miscellanea Curiosa Medico-Physica*, first published in 1670 in Wroclaw (then the German city of Breslau), the world's first journal of natural science and medicine and still in print today.

19 Hill (1965, pp. 37–52) describes Gresham College with great enthusiasm, but Harkness (2007, p. 120) has noted that the lectures were not very popular and the lecture halls were often half empty.

et de Sculpture in 1648). Institutionalization implied a modified and perhaps more efficient functioning of the Republic of Letters. Henry Oldenburg, the Society's secretary, became one of the most effective "intelligencers" ever, even more effective as a node in the communications network of the age than his predecessors Hartlib and Dury. As secretary of an official and formal organization, he acquired an authority reinforced by the publication of the *Philosophical Transactions* starting in 1665. Moreover, the Royal Society, by placing its stamp of approval on scientists, served de facto as an accrediting agency, which in turn increased its own status (Hunter, 1995b, pp. 130–31).

In the eighteenth century the movement toward formalized and sponsored organizations grew, not only in Britain but also through all of Europe. None of this was easy and smooth. The academies struggled with funding, sponsorship, and at times were resisted by universities, who viewed the academies as rivals (Heilbron, 2003a). The *Preußische Akademie der Wissenschaften* was founded in Berlin in 1700 at the suggestion of Leibniz, but it was not until 1744 that it was reorganized in an effective way and funded by Frederick the Great (who appointed a French scientist, Maupertuis, as its director). Informal organizations and *salons* remained major centers for the diffusion of knowledge. As Stewart (1992) has shown in great detail, public science involved a variety of informal groups meeting in coffeehouses, taverns, and people's homes as well as itinerant lectures presented to ad hoc audiences. The transformation from the informal Renaissance academies to the formal and official bodies sponsored by the state was far from complete by the end of the eighteenth century. And yet formal and official academies and centers of learning conveyed many advantages to the scientific community, not least of which was the social prestige and possible patronage associated with being a FRS or an *académicien.* To some extent, formal academies replaced the princely courts as the locus of patronage and the source of legitimacy for intellectuals (Biagioli, 1990, p. 36), and they coordinated and organized the reputation mechanism that remained central to the functioning of the Republic of Letters. However, there was a great deal of continuity here between the age of Enlightenment and the previous century, and informal meetings in salons and country inns remained part of public science.

When all is said and done, cultural evolution and the growth of useful knowledge, whether codified or tacit, was shared by only a minute percentage of the population in only a few nations. The cultural changes affected first a few thousand, then a few tens of thousands of people in pre-Industrial Revolution Europe; democratic instincts notwithstanding, we must concede that what the large majority of workers and peasants knew or believed mattered little as long as there were enough of them to do what they were told by those who knew more. Economic change was driven by upper-tail human capital. Adam Smith expressed this kind of elitism when he noted that "to think or to reason comes to be, like every other employment, a particular business, which is carried on by very few people who furnish the public with all the thought and reason possessed by the vast multitudes that

labour." The benefits of the "speculations of the philosopher ... may evidently descend to the meanest of people" if they led to improvements in the mechanical arts (Smith, 1978, pp. 569–72).[20]

Just as the Republic of Letters was an elite phenomenon, the technological thrust of the Industrial Revolution was the result of the actions of a small and select group. Some economic historians, in their justified anxiety to get away from the absurd Victorian hagiography of a few key inventors having carried the entire Industrial Revolution, have tended to go too far in the other direction by implying that unless much or most of the population had access to education and technical knowledge and were richly endowed with human capital, the emergence and spread of new techniques would be limited. The truth is somewhere in between; it is undeniable that technological progress during the Industrial Revolution was an elite phenomenon, carried not by a dozen or two of big names who made it to the textbooks, but by the thousands—but not hundreds of thousands—of trained engineers, capable mechanics, and dexterous craftsmen on whose shoulders these inventors could stand, the upper tail of the human capital distribution (Meisenzahl and Mokyr, 2012; Squicciarini and Voigtländer, 2015). Technological advance in the period of the Industrial Revolution was a minority affair; most entrepreneurs and industrialists of the time were not like Matthew Boulton or Josiah Wedgwood and had little knowledge of or interest in science or even innovation, just as most landowners were not improvers. But the dynamics of competition in a market economy are such that in the long run, the few drag along the many.

20 Soame Jenyns, a mid-eighteenth-century writer, advocated ignorance for the poor as "the only opiate capable of infusing the insensibility which can enable them to endure the miseries of poverty and the fatigues of the drudgeries of life." See Jenyns (1761, pp. 65–66). As Rosenberg points out, the Smithian view was that such a division of knowledge was increasingly pertinent to a sophisticated ("civilized") society in which specialized "philosophers" would account for technological progress. Compare Rosenberg (1965, pp. 134–36).

generation to the next" (Landes, 1983, p. 33).[49] Open science was the best guarantee for the continuous cumulative nature of the useful knowledge: every discovery and every invention was expected to be placed in the public realm. The Patent Offices of Europe, despite their declared purpose as an organization that constrained the adoption of new technology, reinforced this trend, since detailed descriptions of inventions had to be submitted with the applications.

49 Landes's interpretation of Chinese technological history could be seen as one-sided and a bit simplistic; he fails to mention the continued improvement of Chinese clocks under the Yuan (Mongol) dynasty in the thirteenth and fourteenth centuries, especially through the work of Guo Shoujing. Yet even experts critical of Landes's approach concede that after the fall of the Yuan, while clockmaking was not altogether eradicated, there remained little evidence of its former glory: "when the Jesuits arrived carrying their 'bells that rang by themselves,' there was little evidence remaining to disprove their impression that the Chinese had no knowledge of clockwork" (Pagani, 2001, pp. 12–15)

Chapter 17

China and the Enlightenment

If the argument that the European Enlightenment was a critical factor in Europe's subsequent development is accepted, even in part, the question why other civilizations did not undergo a similar transformation must arise. One answer is that it would be Eurocentric to suggest that just because Europe experienced this cultural transformation and just because it was a stage in the path to economic growth, no other paths were available. Another argument, which I find more appealing, is that China indeed experienced a movement comparable to the European Enlightenment, but it was sufficiently different that it led to a rather different set of outcomes. The advance of science and technology that enrich a nation depends critically on the cultural beliefs of those in the upper tail of the human capital distribution, that is, the intellectual and technical elite. Could it be that one of the keys to the Needham puzzle is to be found there?

A simple argument that China never had an Enlightenment and therefore did not have an Industrial Revolution is incomplete and misleading. Some of the developments that we most closely associate with Europe's Enlightenment remarkably resemble events in China, but the differences between the European and the Chinese Enlightenments are as revealing as the similarities. Late Ming China experienced the rise of an intellectual movement known as *shixue* or "concrete studies." Given the ambiguities in the meaning of the term, we should not read any modern concepts into it. Yet it is often taken to mean "practical matters" such as water control, military science, and administration, as well as knowledge that is in some sense verifiable. It expressed an antipathy for cramming for imperial exams and the detached and pedantic textual scholarship dominating intellectual life in China at the time (Rowe, 2009, p. 59). Either way, a great deal of intellectual innovation was associated with it. Some of that knowledge was borrowed from the West (mostly through the Jesuits and the books they brought along), some of it was indigenous (Jami, Engelfriet, and Blue, 2001, pp. 12–14).

Another crucial element largely missing in China was the institutional bridges that eighteenth-century Europe built between those who possessed propositional knowledge and those who controlled prescriptive knowledge. In engineering, mechanics, chemistry, mining, and agriculture, the *savants* and the *fabricants* in China were as far or further apart as they ever were in Europe.[1] The information flows between those who knew things and those who made things were far narrower and weaker in China than in Europe, and the realization that this connection held the key to progress in the future was missing in the East.[2] Needham noted that the real work in engineering was "always done by illiterate or semi-literate artisans and master craftsmen who could never rise across that sharp gap which separated them from the 'white collar literati'" (Needham, 1969a, p. 27).[3] The Baconian emphasis on creating communications not just within the scholarly community and between scholars and people in power, but eventually also between the realm of the scholar and those of the manufacturer, the farmer, and the navigator, redefined the agenda of research in Europe. Needham (1969a, p. 142) notes that Chinese scholars, masters of the ideographic characters but quite far removed from their own artisans, continued for a long time to "harp on the primitive theories of the five elements and the two principles of *yang* and *yin*." Only rarely, he notes, did exceptional individuals in China break through these barriers. In Europe, as we have seen, such individuals were more common. Moreover, European culture strove to place best-practice scientific knowledge and the investigative techniques used by natural philosophers at the disposal of technological innovators, thus aiding and supporting technological progress. We cannot say that no attempts were made in this direction in the last two centuries of the Chinese Empire, but in the end they could not overcome the obstacles that the entrenched incumbency placed in its way.

1 Needham points out that the Greek distinction between theory and practice, the former suitable to a gentleman and the latter not, has a precise equivalent in the Chinese distinction between *hsüeh* and *shu* (Needham, 1969a, p. 142).

2 In the early eighteenth century Hu Hsu, a famous scholar in his time, complained that the vast bulk of peasants, artisans, and merchants were not part of the educational system and left almost entirely ignorant (Woodside and Elman, 1994, p. 529). The matter is well summarized by Nathan Sivin (1995, ch. VII): "Science was done on the whole by members of the minority of educated people in China, and passed down in books. Technology was a matter of craft and manufacturing skills privately transmitted by artisans to their children and apprentices. Most such artisans could not read the scientists' books. They had to depend on their own practical and esthetic knowledge."

3 Bodde (1991, pp. 224, 367) has similarly argued that there was an "enormous distance between 'white collar' and 'blue collar' workers" in China, and that Chinese science was pursued primarily by learned scholars schooled in the classics. Hence technological progress was carried primarily by poorly educated artisans and skilled craftsmen and not by intellectuals. That served China well as long as innovation was carried out primarily by skilled artisans through experience and serendipity, and did not require injections of propositional knowledge—as was the case in Europe before 1700 as well. The gap between the two began to widen precisely after that, when insights from science were needed to keep the momentum of technological change going instead of petering out, as they did in China (Lin, 1995).

The Chinese counterpart to an Enlightenment movement in the seventeenth and eighteenth centuries was known as the school of *kaozheng* or "evidentiary research." In this school, abstract ideas and moral values gave way as subjects for discussion to concrete facts, documented institutions and historical events (Elman, 2001, p. 4). Chinese scholarship of this period was "not inherently antipathetic to scientific study or resistant to new ideas" (De Bary, 1975b, p. 205). It was based on rigorous research, demanded proof and evidence for statements, and shunned leaps of faith and speculation. It all sounded quite promising, but in the end it led to a different outcome than in Europe. Chinese scholars were primarily interested in philology, linguistics, and historical studies, "confident that these would lead to greater certainty about what the true words and intentions of China's ancient sages had been and, hence, to a better understanding of how to live in the present" (Spence, 1990, p. 103).[4] Equally significantly, unlike the European Enlightenment, the Chinese movement remained by and for the Mandarinate, the ruling neo-Confucian elite, which by most accounts had little interest in material progress.

An early attempt at intellectual innovation that was more or less contemporaneous with Europe's growing criticism of the ancients can be traced to the writings and career of Li Zhi (1527–1602), a philosopher of heterodox inclinations, who actually seems to have felt that one did not have to be a Confucian scholar to be a philosopher, a truly iconoclastic position for the time (Jiang, 2001, p. 13). Views that are similar to those we associate with the European radical Enlightenment were expressed by Li, including that self-interest was part of human nature and was not to be condemned, and that the pleasures of the flesh might be both virtuous and therapeutic. In his correspondence with Geng Dingxian (1524–1594) he makes a point supporting the moderns against the ancients. He quotes Confucius's *Analects* to say that it is better to be "impetuous and uncompromising" than "sanctimoniously orthodox" and accuses Deng of "following old paths and treading in earlier footsteps" (Brook, 2010, p. 180). Huang (1981, p. 204) points out that Li's views were a threat to the neo-Confucian orthodoxy built on the writings of Zhu Xi, and that if it were accepted that individuals could achieve the Great Unity in their own minds, much of the Confucian formal canon could be dispensed with. Such views would constitute a serious threat to the empire, "the integration of which relied to a large degree on the general acceptance of orthodox teachings by the educated elite." At least in that sense Li might have been regarded by the establishment to be as serious a threat as Martin Luther was in Europe a generation or two earlier. Yet in China, the

4 Specifically, *kaozheng* learning was focused on exegesis of the ancient canon: determining authenticity and meaning, and analyzing the etymology and paleography of ancient Chinese characters. This turn toward the ancients affected the civil service examinations throughout the empire. See Elman (2013, p. 275).

battle faced by potential cultural entrepreneurs was far much more uphill.[5] Even the enfeebled late Ming empire could coordinate the suppression of subversive ideas better than the European states could.

Moreover, Li was no Galileo or Bacon. His concern was almost entirely an attempt to reconcile the undeniable private needs and desires of human beings with the obvious constraints of public morality (Huang, 1981, p. 198). In any event, his heterodox views were extremely costly to him: following the publication of his heretical book *A Book to Burn*, he was arrested by the emperor's guard, jailed, and committed suicide in prison (Huang, 1981, pp. 189–221). It is not entirely clear to what extent Li's heretical writings contributed to his fate, as opposed to his lifestyle and his pugnacious character. Moreover, there were other late Ming writers whose works were quite heterodox: Jiang provides a list of innovative writers of that period led by Wang Yangming (1472–1529). Wang was a successful and influential critic of Zhu Xi's thought, proposing a more idealist and egalitarian philosophy, arguing that morality was innate and not learned, and complained that Zhu Xi and his school had replaced moral action with the study of morality. Wang's followers concluded that studying the classics was less useful to moral knowledge than meditation—a view that was quite anathema to the neo-Confucian unity (Brook, 2010, pp. 163, 183). There seems to be little evidence that such criticism hurt his career as a general and administrator. Wang's views established a competing form of neo-Confucianism, with Zhu Xi-ism associated with the status quo and the established authority (Bol, 2008, p. 99). For a while the more liberal approaches of Wang and those influenced by him might have seemed to open the door to a more pluralistic approach to knowledge in China, all within the traditions of neo-Confucianism.[6] Wang's career shows that the market for ideas in China clearly was to some extent competitive and not invariantly hostile to critique of the orthodoxy. Yet intellectual life remained dominated by the civil service examination system, in which innovation, pluralism, and contestability were largely stigmatized—indeed the growing monopoly of neo-Confucianism provided the administration with a tool to fight off challenges to the status quo posed by Wang and his followers (Elman, 2013, p. 81).

Other attempts at serious intellectual reform were made in China in the period under discussion. It could well be argued that the seeds of a Chinese Enlightenment were sown by Fang-Yizhi (1611–1671), the author of a book meaningfully titled *Small Encyclopedia of the Principles of Things*,

[5] Brook (2010, p. 182) assesses that Li may be seen by modern scholars as a martyr for intellectual autonomy, but to his contemporaries he was "a crazy old man."

[6] Needham compares Wang's views to those of such giants of Western philosophy as Berkeley and Kant, but adds that "unfortunately all this, sublime though it was, could hardly be sympathetic to the development of natural science. ... Wang could never understand the basic principle of scientific method" (Ronan and Needham, 1978, p. 252).

which discussed potentially useful forms of propositional knowledge such as meteorology and geography. He was familiar with Western writing and was in close touch with Johann Adam Schall von Bell, a Jesuit missionary scientist residing in China. Early on, Fang was quite influential in the *kaozheng* school of the eighteenth century and his life and works serve as a good reminder of the different history China could have had if circumstances had been different. Peterson (1975, pp. 400–1) has gone so far as to suggest that Fang was representative of the possibility in the seventeenth century that the realm of "things" to be investigated would center on physical objects, technology, and natural phenomena.[7] He argued that Fang's work paralleled the secularization of science in Europe. The real question, then becomes, what was different about China that prevented Fang from becoming a cultural entrepreneur comparable to Bacon or Galileo, so that his new ideas remained only a "possibility"?[8] The *shixue* movement representing a strong interest in natural phenomena and technical writing, in the view of modern scholars, "all but disappeared during the subsequent [Qing] dynasty" to make room for more textual, backward looking intellectual activity (Jami, Engelfriet, and Blue, 2001, p. 14), although the exact difference between the *shixue* and *kaozheng* schools is still in dispute. There is a consensus today that with the rise of the Qing, Chinese science, in Elman's words "turned inward towards native traditions of classical learning" and "during the Newtonian century in Europe Chinese scholars simultaneously focused on restoring native medicine, mathematics, and astronomy to admired fields of classical learning worthy of literati attention. ... These developments were not challenged until the middle of the nineteenth century, when modern Western medicine and technology became insuperable and irresistible" (Elman, 2005, pp. 220–21).

All the same, the literature about the "Chinese Enlightenment" may have overstated its bias toward literary and philological topics. The arrival of the Jesuits to China in the late sixteenth century stimulated a revival of interest in astronomy and mathematics, and Chinese scholars carefully examined useful knowledge that seeped in from the West (Jami, 1994). *Kaozheng* scholars such as Mei Wending (1633–1721) compared Western mathematics and astronomy to Chinese knowledge, and pointed to the advances that the West had made. Yet Mei's rhetoric in his book *Lixue yiwen* (*Doubts Concerning the Study of Astronomy*, 1693) illustrates the fundamental constraints that the accumulation and application of useful knowledge in China was subject to.

[7] Sivin (1975, note n) is far more skeptical of Fang's abilities and has compared him with European scholasticism, feeling that his work was "antiquated."

[8] Fang himself ended up spending his last twenty years as a Buddhist monk, perhaps because he did not want to serve the new Qing rulers. He seems to have lost his interest in Western learning in later years, and there is no evidence that his ideas were pursued further (Engelfriet, 1998, p. 358). Peterson (1979, p. 12) stresses that Fang was considerably less influential than his contemporaries Gu Yanwu (1613–1682) and Huang Zongxi (1610–1695).

In Mei's work, the moderns are in no way superior to the ancients, and there is no progress in history; indeed "the accumulation of human knowledge is merely a token of the ancients' superior merit" (Jami, 2012, p. 220). While the *kaozheng* scholars recognized that the study of mathematics and astronomy was essential to their documentary studies, their ideas were not translated into action and they were focused on understanding ancient texts rather "than in applying their knowledge to practical concerns" (Jami, 1994, p. 227).

Perhaps most remarkable was the late Ming dynasty official Xu Guangqi (1562–1633). Xu's career and views in some ways mirror those of his contemporary Francis Bacon and shared Bacon's belief in what is known in China as *shiyong*, the practical application of knowledge in pursuit of social order (Bray and Métailié, 2001, p. 323). His commitment to learning was motivated by the conviction that it could be used to save the country, not only by military means, but also by applying science and technology to make the country prosperous and powerful (Qi, 2001, p. 361). In that regard, his beliefs are distinctly reminiscent of Bacon's, despite the obvious differences. Xu was a high-level official in the imperial administration (at the time of his death he was both deputy prime minister and minister of "rites," roughly speaking, culture and education). He was responsible for reforming the Chinese calendar based on more accurate astronomical data he learned from the Jesuits, who had access to the work of Brahe and Kepler. Remarkably, he converted to Christianity in 1603 (subsequently becoming known as "Dr. Paul") and was a close collaborator of the Jesuit missionary Father Matteo Ricci, with whom he translated Euclid's *Elements of Geometry*. Perhaps his most astonishing contribution was his monumental *Nongzheng quanshu*, an agricultural treatise published posthumously in 1639 that summarized much existing knowledge of Chinese agriculture, but also illustrated his firm belief in the importance of experimentation to augment agricultural knowledge. The book was vast, containing 700,000 Chinese characters (Bray, 1984, p. 66). It was, by the standards of that time on any continent, full of progressive ideas. Xu reported a great deal of agricultural experimentation, at least some of which he carried out himself. He also advocated the new crops that were being introduced into China from the New World, and condemned conservative farmers reluctant to adopt new crops, such as sweet potatoes because of their mistaken belief that crops will only grow well where they originated (Bray and Métailié, 2001, p. 341). He had a practical intellect and endorsed concrete studies (*shixue*); Xu's work perhaps serves as an indication of where Chinese intellectual innovators could have gone had they lived in a different polity (Zurndorfer, 2009, p. 82).

None of the late Ming writers directly challenged and refuted the basic canon of Chinese metaphysics. All the same, De Bary (1975a, p. 5) and Jiang (2001) note that the various modernizing and innovative views of the world thrived in a limited way in the late Ming period.[9] Jami (2012) and others have suggested that the rise of the Qing dynasty was decisive for the fate of the development of science in China and that what little there was of a stirring of intellectual progress before 1644 could not survive what De Bary has called the "Manchu suppression." In the late eighteenth century, the Qianlong emperor's administration cracked down on intellectuals in what has become known as the "literary inquisition." The suppression was aimed more at scholars suspected of anti-Qing sympathies than at intellectual innovators per se, but it is believed to have inflicted long-lasting damage on the Chinese intellectual class and the formation of human capital (Koyama and Xue, 2015).[10]

Moreover, to make Western learning more acceptable, Chinese scholars had to convince the officials, especially those of the Qing dynasty, that most of it had Chinese origins, thus conferring on it a status comparable to Chinese traditional knowledge and thus legitimizing it. Mei Wending convinced the Kangxi emperor that European learning was derivative from the Chinese and that the only source of reliable knowledge was the ancient learning of China (Elman, 2005, pp. 231, 236). The new astronomical knowledge, such as the precise shape of the earth, while in its current version originating in Europe, was said to have been present in China all along and thus was not foreign at all (Jami, 2012, p. 222). The need of Chinese scholars to show that Western knowledge had already existed in ancient China indicated the difficulty they had in ridding themselves of the burden of the ancients. No such need to assert their own originality seems to have been present in Europe. Europeans borrowed useful knowledge freely and shamelessly from foreign civilizations, acknowledged their debts to earlier generations, but then went on to expand this knowledge and improve the techniques. The contrast with China is stark: one scholar has concluded (with some exaggeration) that "by 1800, there was no sign that China had been persuaded to adopt European knowledge on a large scale ... and that European knowledge was able to fundamentally affect ordinary Chinese life" (Deng, 2009, p. 62).

While the Chinese scientists did at times adopt European tools that they clearly did not possess, they did little to improve them beyond what the Europeans had done. An example is the adoption of the telescope, clearly a European invention, to the study of astronomy (Huff, 2011, pp. 110–14). While the telescope was introduced into China by the Jesuit missionaries,

[9] All the same, the death of Li Zhi and a similar fate that befell another heterodox writer of his age, Tzu-po Ta-kuan (1544–1604), led a contemporary to note that "if anyone behaved like a heretic, he will of course be killed. Li Zhi and Ta-kuan are good object lessons" (Kengo, 1975, p. 60).

[10] Mote (1999, p. 928) notes that pervasive fear of persecution led many intellectuals to destroy books in their possessions rather than face the chance of discovery and punishment.

their star catalogs were not expanded at a rate comparable to that achieved by telescope-equipped European astronomers, such as John Flamsteed. Huff attributes this difference to a "curiosity deficit" in China, but one cannot understand this difference without a deeper examination of the institutional and political environment in which the accumulation of useful knowledge operated.

The tradition of *kaozheng* scholarship contained many elements that we associate with the European scientific revolution and the subsequent Enlightenment (Elman, 2001). Kaozheng scholars developed an efficient network of information exchange and correspondence. The Jiangnan (Yangzi delta) area, in which many of the kaozheng scholars resided, counted many libraries, and the lending of books was a universal custom. In Beijing an entire street was a major book emporium, and much like in Europe, the publishing industry printed novels as well as classical texts. In the late Ming period Jiangnan books fell in price and attained wide popularity and circulation (Elman, 2005, p. 29). Much like their European counterparts, Chinese scholars agreed that mathematics was one of the keys to concrete studies, as Jiao Xun (1763–1820) put it. Much like in Europe, too, information was organized in tabular form, and often illustrated by diagrams and maps. Gu Donggao's (1679–1759) book used them for information on the pre-Qin and Han periods (722–481 BC) and Yan Roju (1636–1704) counted and analyzed citations from classical poetry. The scientists of the early Qing period were convinced that their mathematical tools (trigonometry and geometry) had the power to explain nature as well as to predict it. Yet, as Nathan Sivin (1975, p. 161) notes, "in China the new tools were used to rediscover and recast the lost mathematical astronomy of the past and thus to perpetuate traditional values rather than to replace them."

Unlike Europe, Chinese intellectuals found it difficult to shake loose from the iron grip of the past. Mathematics, medicine, and most other forms of useful knowledge were studied and reflected on, but remained mostly a branch of classical studies. Attempts to apply this knowledge to practical uses were taking place, and when new ideas or products appeared, the Chinese were not averse to them. But unlike their European counterparts, Chinese scholars never came to believe that useful knowledge and its capacity to generate material progress through its applications was one of the raisons d'être of natural philosophy. The wholesale shredding of the wisdom of earlier writers, at times quite impudently so, that was characteristic of many European writers, did not catch on in China. Even Xu Guangqi's massive treatise on agriculture consisted of more than 90 percent citations of earlier writers (Bray and Métailié, 2001, p. 337).

The work of Gu Yanwu (1613–1682), one of the founding intellectuals of the *kaozheng* school, is revealing. Sometimes pictured as a kind of Chinese version of Arthur Young (see for example Morris, 2010, p. 473), Gu's work was emblematic of the new Chinese scholarship in the late Ming era: it was far more rigorous and rational, and was based on extensive

traveling in China, where he acquired first-hand information. And yet Gu's writing provided mostly information based on philology, archaeology, and the careful analysis of early works, and his interests were mostly in historical and textual studies and politics.[11]

An early enlightenment-type author in China was Song Yingxing (1587–1666), the author of *Tiangong Kaiwu* (*The Creations of Nature and Man*), a lavishly illustrated encyclopedic volume on technology completed in 1637 (Song [1637], 1966). Song, who repeatedly failed his civil service examinations, was an astonishingly learned man who was termed "the Chinese Diderot" and the "Chinese Agricola" by Joseph Needham (1959, p. 154; 1986, p. 102). Song's work is especially interesting, because his thinking in some ways was very much in line with his European contemporaries. Precisely because the road to success and social prestige led through scholarship of ancient texts in which ambitious youngsters were trained, most Chinese intellectuals had little interest in new technology and in the expansion of practical useful arts and sciences. Chinese intellectuals were more interested in matters of public administration and governance, and were glad to leave technological issues to craftsmen. Song, perhaps because he never was able to join the ranks of the elite, broke the barrier between natural philosophy and technical knowledge (Cullen, 1990, p. 315). In his preface he states baldly that "an ambitious scholar will undoubtedly toss this book onto his desk and give it no further thought; it is a work that is in no way concerned with the art of advancement in officialdom" (Song, [1637] 1966, p. xiv). Song regarded issues of ritual and morality irrelevant to discussions on human-heaven interconnectedness. As Schäfer points out, this seems to be consistent with the values that came out of the Baconian program, and, in her words, "fits our modern conception of a scientist: someone who suspects indoctrination, challenges contemporary thought, and systematically searches for a rational order in the world that surrounds him" (Schäfer, 2011, p. 54). Cullen notes that his views made him a soulmate of some of the more progressive Europan thinkers such as Bacon, whose influence on the Industrial Enlightenment, as we have seen, was immense. But the difference between the two is as striking as the similarity: Song was not to become the "Chinese Bacon." His work had little impact on the intellectual life of his contemporaries (Cullen, 1990, p. 316).[12] It is also important to realize that even a progressive

[11] His magnum opus, *Ri-zhi-lu* or *Jih-chih lu* (*Daily Accumulation of Knowledge*) is a treasure trove of information, but is definitely stronger on Confucian classics, history, ceremony and administration than on matters of great practical knowledge. See Peterson (1979, pp. 9–12) for details.

[12] Schäfer (2011, pp. 258–82) notes that the book was published twice, with about fifty copies made, though it was not totally ignored either and seems to have circulated among a small circle, where it was of some "quizzical and inadvertent" interest—a far cry indeed from the vast impact that the writings of Francis Bacon made on his contemporaries. No reprints of his magnum opus were made in the Qing period (after 1644), and the resurrection of the work was thanks to the discovery of a copy in Japan that had been brought there in the 1880s.

scholar such as Song thought very differently from his Baconian contemporaries. Schäfer (2011, p. 117) notes that he would have "laughed at any suggestion that the talented scholar should engage in the practice of craftsmanship or vice versa that a craftsman should try scholarly work. In fact, he insisted that ... the idea that a person from one group could appropriate the knowledge of the other would not work." China, much like Europe, had multi-talented individuals who spanned both theoretical and practical knowledge, but unlike Europe the vast majority of intellectuals regarded themselves entirely as scholars and their discourse was solely with other learned persons.

Another example of how the Chinese Enlightenment differed from Europe's is a later scholar, the philosopher Dai Zhen (or Tai Chen, 1724–1777). Dai Zhen was one of the dominant figures in the *kaozheng* movement, and his insistence on evidence and his mathematical capabilities would appear to make him comparable to European contemporaries. One historian described him as someone who was "a truly scientific spirit ... whose principles hardly differed from those which in the West made possible the progress of the exact sciences" (Gernet, 1982, p. 513). Yet while Dai was sharply critical of the neo-Confucian school sometimes known as the Cheng-Zhu school (after the names of its founders), Gernet immediately adds that the erudition of this research went hand in hand with the renunciation of any attempt at reflection and synthesis and that its research into historical details became an end in itself (Gernet, 1982, p. 516). Thus, Dai reinterpreted the writings of Confucius and tried to reconcile the teachings of two of Confucius's most illustrious followers, Mencius and his opponent Xunzi. He criticized the writings of Song era authorities such as Zhu Xi, but largely on the grounds that the latter had misinterpreted earlier sages, not on the basis of observation or experiment. While insisting on evidence, Dai did not mean by it anything that Galileo or Boyle would have been interested in—for him the focus of research was philology and phonology, exegesizing the writings of earlier generations.[13] Nothing was to come between the scholar and his careful study of the classics, and what "the student of the Way needs to do is to approach the classical text with an open mind, without preconceptions." He thus objected to the neo-confucian orthodoxy, but purely out of fundamentalism, and he viewed education as "utterly and eternally dependent on the classics" (Brokaw, 1994, pp. 269, 277).

A generation before Dai, and no less impressive, was Chen Hongmou (1696 –1771), a professional administrator who wrote widely on what may best be called political economy and public administration. As Rowe (2001, p. 114) shows, Chen was an unusually progressive scholar, who in some ways resembled the physiocrats and Adam Smith and decried the

[13] As Elman (2005, p. 259) points out, Dai Zhen engaged in a systematic research agenda "that built on paleography and phonology to reconstruct the meaning of classical words." His followers extended his approach and attempted to use etymology to reconstruct the true intentions of the sages, defending them from the neo-Confucian philosophy of the state.

ivory-tower antiquarianism of the *kaozheng* scholars, who he thought were too "mired in the past." He strongly believed in markets and the power of commerce to bring out efficiency in production and came close to Smith's concept of an invisible hand. Rowe (2001 p. 214) points out that the one element that Enlightenment Europe had, which was entirely missing in Chen, is the strong belief in the economic virtue of emulation, which was a central element of the European Enlightenment ideology. But equally striking is the absence in his work of a concept of useful knowledge as a source of economic progress.[14] Chen was deeply interested in creating prosperity, and his proposals included active economic policies to encourage mining, commerce, and manufacturing. He instinctively understood incentives and tried to bring more rural workers into a system of domestic manufacturing, in which state intervention at the provincial level would be the main moving part. But significantly, technological progress and a more active role for useful knowledge were not central to his thinking. Agriculture, where technology was perhaps most important in his thought, would be improved by introducing crops already cultivated elsewhere into Shaanxi province. But the emphasis was not on innovation per se as much as it was on the dissemination of existing knowledge. The "Confucian moral tone" assumed the short-sightedness of an ignorant population of local peasants, "which the better-educated and more widely experienced official was beholden to overcome" (Rowe, 2001, p. 232).[15]

The *kaozheng* medical literature had its own debate on ancients vs. moderns, but ironically it differs from Europe's in two critical dimensions: first, the ancients were the classical writers of the Han dynasty (206 BC to 220 AD), and the moderns were the writers of the Song era (still three or four centuries in the past), and second, that the *kaozheng* scholars favored the *earlier* writers (Elman, 2005, pp. 232–36). There were no Chinese equivalents of Paracelsus, Vesalius, and Harvey, who threw all caution to the wind and trusted only what they (believed they) saw. Little wonder, then that the verdict of historians has been that "this scientific spirit was applied almost exclusively to the investigation of the past"(Gernet, 1982, p. 513).

It might be thought that the backward looking character of China's intellectual life during the Ming and Qing dynasties is surprising. After all, China was a society without an institutionalized religion. It did not have a

[14] To be sure, such a concept is also largely (if not entirely) absent from Smith, whose vision of economic growth was primarily based on trade and the division of labor.

[15] It is striking that Chen was a "loyal devotee" of the conservative Song era historian and statesman Sima Guang, whose biography he wrote and whose works he edited. While he was, in Rowe's terms, more "developmental" than Sima, there is little in his writings that suggests a Baconian belief in the progressive powers of useful knowledge (Rowe, 2001, p. 287). It is indeed striking that his discussion on "accumulation" includes almost nothing on an expansion of new productive assets and techniques, and it is instead wholly focused on the topic of price stabilization through granaries.

caste of priests, rabbis, or mullahs whose power and livelihood depended on their interpretation of the sacred writings of the past making them highly intolerant of apostasy. But religiosity is neither a necessary nor a sufficient condition for intellectual conservatism. One explanation of its backward-looking orientation surely is the large investment of human capital of ambitious and bright Chinese youngsters in the learning of the past, in the hope of passing the civil service examinations. The bulk of candidates failed these exams in local competitions, and hence large reservoirs of classically trained men were desperately looking for ways to extract some rents from their human capital. These people also constituted a vast audience for the books published at the time. Furthermore, the first three Qing emperors, who ruled for more than a century, sought to appropriate the classical legacy to "establish their dynastic prestige and political legitimacy" (Elman, 2005, p. 238). But more generally, the skepticism toward the knowledge of earlier generations that awoke in Europe after 1500, as more and more beliefs of ancient authorities were questioned, tested, and found wanting by European scientists and physicians, was rarely allowed to arise in China.[16]

A telling example is the publication of Chinese encyclopedias. As I have argued elsewhere (Mokyr, 2005), European encyclopedias are emblematic of a main theme of the Industrial Enlightenment in that they were explicitly meant to reduce access costs and make useful knowledge available to those who could make use of it. By organizing large bodies of knowledge in single publications, they showed their eagerness to distribute the knowledge to the curious and to those who might want to use it. Yet such compendia also contained conservative elements, because they present a snapshot of present accumulated knowledge, unless they were constantly updated and replaced. European encyclopedias, it was universally realized, went out of date almost as soon as they were published, and hence they were quickly replaced.

Europeans were not the only ones to realize the importance of reference books. But there was a critical difference: while European reference books were made accessible to a wide public, in China they were typically limited to a very narrow audience of mandarins in power. Wang Zhen's *Nong Shu* (*Treatise on Agriculture*), completed in 1313, foreshadowed the best works of the European Enlightenment: its more than 300 illustrations of tools and machinery were rendered with such accuracy that they could be made from the illustrations, as was the author's intention (Elvin, 1973, p. 116). However, in 1530 there was just one copy left in all of China, and it had to be reprinted. Another early example was the vast *Yongle Dadian,* compiled by the Ming Emperor Yongle between 1403 and 1408, which contained a massive amount

[16] Even an author like Jack Goody, who goes out of his way to condemn "essentialist" interpretations of Chinese history, writes that "characteristic of the cultural history of China has been a constant looking back to the Confucian classics, to 'Antiquity,' providing a continuous point of reference for both conservatives and reformers" (Goody, 2009, p. 238).

of information on science, technology, religion, history, and literature among other things. Because of the size of the work, it could not be blockprinted, and only three copies were made, the third one in 1557 after a palace fire threatened the survival of the work. Access to the work was limited to the emperor himself, unless special dispensation was granted (McDermott, 2006, pp. 126–27). Another example is the equally voluminous *Bencao Gangmu* (*Compendium of Materia Medica*), written by the herbalogist Li Shizhen in the late sixteenth century, which contained a complete list of all medical plants, herbs, and substances (1,892 of them, in fifty-three volumes) believed to have medicinal properties. This was not just a regurgitation of old materials, as it includes references to syphilis, and sweet potatoes, both of which had New World (and thus recent) origins. Even larger was the *Gezhi congshu*, a "repository of classical, historical, institutional, medical, and technical works from antiquity to the present [i.e., late Ming times]" (Elman, 2005, p. 34), a collection of books (completed ca. 1603) that included all knowledge important to educated people prior to the arrival of the Jesuits. These books embodied the great respect in which the Chinese held the learning of previous generations, and they crystallized as much as disseminated the body of useful knowledge.

Unlike Diderot's encyclopedia, these compilations were not widely disseminated. One widely traveled early Qing scholar, Lio Xanting (1648–1695), complained that in ten years of searching he had not been able to find a single copy of Xu Guangqi's *Nongzheng quanshu* (Bray and Métailié, 2001, p. 355).[17] No new edition appeared for two centuries. As we have seen, Song Yingxing's magnificent *The Creations of Nature and Men*, survived only because an accidental copy had found its way to Japan. Of the enormous collection put together by Hu Wenhuan, the compiler of *Gezhi Congshu*, only 181 of 346 remained extant in the late eighteenth century (Elman, 2010, p. 381).

The efforts to organize knowledge in a systematic way were continued after the overthrow of the Ming in 1644. The vast efforts of the Chinese Qing emperors to publish encyclopedias and compilations of knowledge under the Kangxi and Qianlong emperors—above all the massive *Gujin tushu jicheng* compiled by Chen Menglei and published in 1726 (one of the largest books ever produced, with 10,000 chapters, 850,000 pages and 5,000 figures)—indicate an awareness of the importance of access to information. It was printed at the Wuyingdian, the Imperial Printing Office in Beijing. Altogether about 60 copies were made of it, a number that pales in comparison to the European encyclopedias, which were sold in large numbers.[18]

[17] Bray also notes (1984, p. 70) that Xu's detailed program of reforming agricultural administration was never put into practice.

[18] Darnton (1979) has estimated that in total, d'Alembert and Diderot's *Encyclopédie* sold about 25,000 copies. Given the many competitors in many languages that came out in the eighteenth century, and not counting the many compendia, dictionaries, lexicons, and similar

It is also revealing that Chen was arrested and deported (twice), and his name was removed from the project by the emperor whose wrath he had incurred. The entire project was carried out under imperial auspices and was a project of, by, and for the imperial bureaucracy.[19] Chen Yuanlong's (1652–1736) parallel project, an equally vast compilation named *Mirror of Origins,* contained almost no European learning, because the Kangxi emperor believed that all learning originated in China and his son, the Yongzheng emperor, disliked the Jesuits. The last of those massive works, commissioned by the Qianlong emperor in 1773 and completed in 1782 was the *Siku quanshu* (*Library of the Four Treasuries*), another huge work with 360 million words, filling 36,000 large folio volumes. Altogether seven copies of this work were made, four of which were kept at the imperial palace, although after 1787 access for scholars and literati opened up (McDermott, 2006, p. 168). In Europe, by and large, encyclopedias and reference books were the product of private enterprise, sometimes published very much against the will of authorities powerless to stop them. It stands to reason that some of the reference books produced in China served candidates for the state examinations and perhaps "to help the mandarins in their work" (Burke, 2000, p. 175).

Even ordinary books, moreover, did not circulate much. China had public libraries, and in the Song years they were reasonably accessible and promising young scholars were allowed to spend a few years studying in them. Over time, however, theft, fires, and wear and tear reduced the size of the collections. By Ming times, these libraries were reduced to a small fraction of the books they were supposed to own. Public libraries were hardly centers of learning, and the big concentrations of books that were in private collections were carefully guarded and thus were inaccessible (McDermott, 2006, pp. 127–47). Things improved under the Qing, when officials sponsored more than 150 editorial projects, with the Qianlong emperor's famous *Four Treasuries* project its crowning achievement, and book-sharing among bibliophiles developed in the mid-eighteenth century (McDermott, 2006, pp. 167–68). Even then, however, access remained a major problem for scholars, especially those living far from the urban centers in the lower Yangzi valley.

The one historical case that purports to illustrate the great divergence of Enlightenment Europe and retrograde China is the famous failed mission of Lord George Macartney to China in 1793, in which the friendly gestures and samples of British ingenuity were allegedly spurned by the aging Qianlong Emperor. The traditional view of this event is that it is an

books published in the eighteenth century, the total number of encyclopedic reference books published in Europe was a large multiple of the sales of the *Encyclopédie*.

[19] One scholar has suggested that, much different from the works of European encylopedists, the *Gujin tushu jicheng* arose from the idea that the emperor's task was to join the whole knowledge of the world to a unified Cosmos (Bauer, 1966, p. 687).

illustration of the large cultural gap that had opened between East and West. In a classic paper, Cranmer-Byng and Levere (1981) argued that the British, "confident in their Industrial Revolution" were committed to an "ideology of progress through science," and Macartney noted in his diary his obvious belief in the superiority of the culture the fruits of which he was carrying to the Chinese. This stood in complete opposition to "the policy of the present [Chinese] government to discourage all novelties." The Chinese were seemingly unable to appreciate the intellectual and theoretical content of natural philosophy, with its potentially enormously useful application (Cranmer-Byng and Levere, 1981, pp. 516, 518). The mission was doomed from the start, because the two countries possessed different cultures with totally different sets of values. This view may overstate the real gap. Cranmer-Byng and Levere (1981) concede that the aging Qianlong emperor had far less interest in science and technology than his grandfather Kangxi, and thus the failure of the Macartney mission might to some extent be explained by accidental factors and was more contingent than was previously thought. More recent scholarship is cautious: "neither Lord Macartney nor the Qianlong emperor could foresee that the Industrial Revolution in England would produce British military superiority ... we should not read the events of the first and second Opium Wars back into the eighteenth century" (Elman, 2005, p. 254). It is also true that Macartney did not actually display some of the most advanced industrial machinery available in Britain at the time. The steam engine model, the Smeaton pulleys, and "assorted chemical, electrical and philosophical apparatus" never reached the Chinese court. In short, it stands to reason that the Macartney delegation brought with it an unrepresentative sample of British mechanical triumphs, and that what they brought had little appeal to the Chinese court.

Yet that the Macartney mission failed, even if it was in part the fault of bad organization and bad luck, is an indication of a deep difference between the celestial empire and the European nations. Chinese officials may still have sensed that the Europeans had something they did not have, as Mote (1999, p. 961) stresses. But they did not react because they felt they did not have to. They were committed to the Chinese model of slow change of what Mote has eloquently described as "self-renovating change that was constant and gradual, not sudden and disruptive, and was always justified by reference to past models" (Mote, 1999, p. 966).[20] An eighteenth-century Confucian scholar named Cheng Tingzuo had nothing but contempt for European science: "Far-off Europe!... Its people are known for their many-sided cleverness, excelling particularly in mathematics. Apart from this

[20] Father Ricci, one of the keenest observers of Chinese society in the late Ming period, noted that when the Chinese realized the superior quality of a foreign product, they might prefer it; but "their pride ... arises from an ignorance of the existence of higher things and from the fact that they find themselves far superior to the barbarous nations by which they are surrounded" (Ricci, 1953, p. 23).

everything else is excessive ingenuity" (cited by Elvin, 1996, p. 97). In that regard, Chinese society was not all that different from Jewish society in early modern Europe: slow development and marginal increments in knowledge within rigid boundaries were tolerated within the constraints of the past. It was a model that worked well and was sustainable and stable, except for one thing: in eighteenth-century Europe a new culture had emerged that questioned and then rejected the wisdom of its canonical forefathers and rebuilt much of the body of useful knowledge from scratch. Such a culture turned out to be more aggressive and was subject to sudden and disruptive changes such as the Industrial Revolution. It inevitably spilled over and affected other cultures that by themselves had a much more quiescent dynamic. There was nothing wrong with China except for what happened in Europe.

To see how China and Europe may have been different, it is useful to return to the concept of cultural entrepreneur. In some eras, especially during the era of the warring kingdoms, China's most creative and original philosophers attained considerable influence and were instrumental in changing the outlook of society and through that, the institutions and performance of the economy. As noted in chapter 16, the most prominent cultural entrepreneur that China produced was Zhu Xi, the synthesizer of neo-Confucianism. The orthodoxy established by Zhu came to its full bloom under the Ming. One fifteenth-century Chinese writer noted that "since the time of Zhu Xi, the Way has been clearly known. There is no more need for writing; what is left for us is to practice" (quoted in Hucker, 1975, p. 373).[21] Such views are exaggerated: the seventeenth century witnessed a flourishing of a diverse and sometimes contentious literature, which one scholar has described as a "vibrant and innovative culture" (Schäfer, 2011, p. 14). Some differences of opinion were possible within the neo-Confucian orthodoxy, which may have been a "fluctuating concept" and not a rigid, fixed body of thought.[22] Within the fluid boundaries of the Zhu Xi orthodoxy, late Ming China experienced a flourishing of studies on a host of natural phenomena including magnetism, hydraulics, and medicine. Yet at the end of the day we do not find a major break with the past and a willingness to shed much of accepted wisdom. Scholarship was not meant for the eventual "relief of Man's estate," as Bacon famously phrased it, but in understanding "the works of heaven" and the "inception of things." That is, when meticulously describing crafts and technology, late Ming scholars hoped that they could learn the principles that would bring about order in the world. In the final analysis, human affairs were not their focus (Schäfer, 2011, pp. 17–18). The

[21] Needham (1969b, p. 66) notes that Zhu has been termed both the Thomas Aquinas and the Herbert Spencer of China.

[22] Thus, for instance, the Ming philosopher Chen Chianzhang (1428–1500) disagreed with Zhu on many points, but "was not a complete break from the dominant trend of his time" (Ng, 2003, p. 36). He was accused of heresy and of being influenced by Daoist and Buddhist thought, but the ruling orthodoxy was sufficiently entrenched that it was not overly concerned.

country, literate and learned as it was, teemed with powerful intellectuals and astonishing polymaths who brilliantly straddled abstract philosophy and mundane areas, comparable with Europe's most admired superstars. All the same, it is hard to discern many spectacularly successful cultural entrepreneurs in imperial China after Zhu. Only after the overthrow of the empire, in the twentieth century, has China seen a number of influential cultural entrepreneurs, although men like Mao and Deng also attained enormous political power, and some of their influence may well have depended on coercion bias. Such intellectual continuity was anything but a weakness, much less a failure. It was the normal state of affairs in human history, only to be broken by exceptional circumstances.

The Chinese approach to knowledge was different in some important nuances from European. It did not "posit the existence of a uniform and predictable order in the physical universe" (Dikötter, 2003, p. 695) and did not rely on the new mathematical tools that allowed the Europeans increasingly to apply their useful knowledge to engineering problems.[23] The nature and characteristics of useful knowledge as it developed in China were not "less" or "worse" than what emerged in the West, just *different*. The ability of Chinese science to serve as an epistemic base for Chinese technology clearly did not work as well if our criterion for working well is the ability to generate economic growth.[24]

Pre-modern Chinese technology, no matter how sophisticated and advanced compared to the European variety, remained grounded on a narrow epistemic base.[25] Except for medicine, where practice and theoretical knowledge inevitably intertwined, and a few Leonardo-like universal geniuses who could do and did everything—such as the astonishing Song dynasty polymaths Shen Kuo (1031–1095) and Su Song (1020–1101)

[23] In a famous essay, Needham (1969a, pp. 299–330) argued that the Chinese never had a concept of a universal scientific law because its religion did not include the concept of a supreme lawgiver. The best they could do, he thinks, is the Taoist concept of empirical regularities that were wholly "inscrutable" and context-dependent and he concludes (p. 311) that "by that path science could not develop." He noted that the European Scientific Revolution was accompanied by the rise of the concept of immutable laws of nature (see also Ronan and Needham, 1978, pp. 290–91). It is hard to see that the centrality of a supreme and omnipotent law giver was much of an advantage to Judeo-Christian theistic religions in developing their useful knowledge. After all, it did little for Islam after Al Ghazali's *kalam* occasionalism became increasingly influential, nor for Jewish science before the nineteenth century.

[24] Nathan Sivin ([2005] 1984, p. 542) has rightly criticized "a saga of Europe's success and everyone else's failure." Yet he himself notes a few pages earlier (p. 537) that "the privileged position of the West comes ... from a head start in the technological exploitation of nature." It is unreasonable to explain such a head start without admitting that something that Westerners learned about nature was different from what was learned in China.

[25] Needham (1970, p. 39) cites with approval the verdict of a ninth-century Arab author that "the curious thing is that the Greeks are interested in theory but do not bother about practice, whereas the Chinese are very interested in practice and do not bother much about the theory."

—Chinese science during that time remained largely separate from technology and production (as it was in Europe at the time).[26] On the whole, Chinese science had little interest in finding out *why* and *how* techniques worked. One might wonder, moreover, whether Chinese craftsmen and engineers might have found much of the science of their world very helpful. It is perhaps telling that although a considerable number of Chinese inventions and techniques found their way to the West in one form or another, there are comparatively fewer instances of Chinese propositional knowledge (not to mention science proper) being adopted in Europe.

As noted, the growing consensus that characterized Enlightenment Europe was a mechanistic view of the universe. There were fixed and clear rules by which nature operated, and humankind's challenge was to discover these knowable rules and take advantage of them. Yet the view that these differences somehow handicapped the Chinese and caused a "failure" can be criticized as an example of the hindsight bias that just because Europe created what became known as "modern science," this was the *only* way that technological progress and economic growth could have occurred. Evolutionary theory suggests that the actual outcomes we observe are but a small fraction of the outcomes that are feasible, and we simply have no way of imagining how Chinese useful knowledge would have evolved in the long run had it not been exposed to Western culture and whether it would not have produced a material culture comparable to the one produced by the European Industrial Enlightenment.

It is clear, in any event, that the Chinese Enlightenment, if that is the right term, did not produce what the European Enlightenment did. Its research agenda included little or no useful knowledge and instead, in one succinct formulation, they were "living out the values of their culture" (De Bary, 1975b, p. 205). Mathematics and astronomy were applied for instance to reconstruct the size and shape of historical ceremonial bronze bells or reconstruct ancient carriages. Even though the *kaozheng* movement was born in part as a rebellious movement protesting the Manchu conquest of 1644, it could not remove itself from the establishment, and its agenda remained largely confined to what the court sponsored. If China's imperial government was not interested in steering research in a direction that could benefit from useful knowledge or the economy, there seems to have been no other agency that had the interest or the capacity to do so. The agenda of Chinese scholarship remained predominantly retrospective: to prove ancient sages right and to perform exegesis on their writings was a worthwhile intellectual activity, but it did not bring about the technological developments that changed the course of world history. It seems wrong to dub the Chinese experience a "failure." What is exceptional, indeed unique, is what happened in eighteenth-century Europe.

[26] For a similar recent view, see Davids (2013, pp. 230–31).

Epilogue

Useful Knowledge and Economic Growth

Nations and their economies grow in large part because they increase their collective knowledge about nature and their environment, and because they are able to direct this knowledge toward productive ends. But such knowledge does not emerge as a matter of course. While most societies that ever existed were able to generate some technological progress, it typically consisted of one-off limited advances that had limited consequences, soon settled down, and the growth it generated fizzled out. In only one case did such an accumulation of knowledge become sustained and self-propelling to the point of becoming explosive and changing the material basis of human existence more thoroughly and more rapidly than anything before in the history of humans on this planet. That one instance occurred in Western Europe during and after the Industrial Revolution.

Many factors contributed to this unique event, and the transformation of elite cultural beliefs in the centuries before the Industrial Revolution was only one of them. The big difference between Europe and the rest of the world was the Enlightenment and its implications for scientific and technological progress. But the rise of the Enlightenment in the late seventeenth century was the culmination of a centuries' long process of intellectual change among the European literate elite. The changes in the market for ideas were the crucial events that set Europe apart from the rest of the world. Europe was not in every respect a better-organized or a more dynamic society than other Eurasian societies. Goldstone (2012, p. 238) suggests that the "intellectual shift that began around 1500, ... limited for centuries to a small circle of scholars and theologians, ... by 1660 had started producing significant changes in the way elites acquired and validated knowledge." Changes in cultural beliefs for a while could move almost independently from changes in other economic variables, such as commercialization, urbanization, and economic growth. Eventually, however, they would feedback into the economy in a direction and with a magnitude that even the most ebullient of the seventeenth-century moderns and most committed believer in progress could not have imagined. In that sense, at least, we can see a major correction to the view that insists that the Great Divergence was a late and temporary phenomenon due mostly to fairly minor and accidental differences in geography. Culture, after all, mattered.

In this book, I have outlined a model of cultural change that explains why the Enlightenment took place in Europe. The question that will inevitably be raised is whether the Enlightenment in Europe was a necessary or a sufficient condition for the great breakthroughs that led to explosive economic growth and the modern economy. Could another and different civilization have eventually broken the Malthusian and knowledge barriers that kept human society at living standards close to subsistence since the beginning of humanity?

We may never know, because the Islamic world, Africa, China, India, and the original societies of America were all exposed to European culture, and their trajectories were irreversibly perturbed. But most societies that ever existed were subject to what I have called elsewhere Cardwell's Law (Mokyr, 1994, 2002), which is a generalization of the phenomenon that technology in any economy crystallizes at some point, and progress slows down and then fizzles out. The stagnation occurs because the status quo can suppress further challenges to entrenched knowledge and blocks nonmarginal advances using a range of means, from the threat to persecute heretics and the burning of their books, to subtle but effective mechanisms, such as meritocracies in which the key to personal success was the uncritical expertise in the existing body of knowledge inherited from the past.

Breaking out of Cardwell's Law requires, above all, a community that combines pluralism and competition with a coordination mechanism that allows knowledge to be distributed and shared, and hence challenged, corrected, and supplemented. Ancient Greece and the Hellenistic culture it created in the eastern Mediterranean, at least for a while, may have enjoyed these attributes and perhaps if it had not been consolidated into Roman rule, it might have evolved into something different. Perhaps medieval Islam, had it avoided the cruel hands of benighted religious beliefs and of the Mongols who destroyed so much of the infrastructure and so many of the institutions that explain its initial flourishing, could have morphed into a world enjoying self-propelled progress.

The correct way to think about the rise of modern science and technology in Europe is to see it not just as the natural continuation of ancient, medieval, and Renaissance culture but also, paradoxically, as its repudiation (Goldstone, 2012). 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 dominated by Jesuits, as imagined for instance in the counterfactual novel of Kingsley Amis (1976). In such a world, out-of-the-box thinkers from Newton and Spinoza to Toland and La Mettrie might have been silenced or sufficiently discouraged, and the Enlightenment might never have taken off.

Would it have been possible for a totally different set of institutions to have created a modern economy? Instead of a decentralized community of competitive scientists and inventors, imagine a New Atlantis run by a central administration in which technological progress is brought about by civil servants supported and sustained by a benign and progress-minded bureaucracy. Could such an organization have brought about the modern world without anything resembling the European Enlightenment? The economist's logic would probably judge such a scenario as unlikely. It is one thing for such a political situation to be brought about in a single period; the likelihood that it could be sustained and avoid being corrupted and disrupted by greedy and ignorant outside invaders or inside rent-seekers in the long run seems dim.

To see the true importance of the European Enlightenment in the economic developments that followed it, recall that it involved two highly innovative and complementary ideas: the concept that knowledge and the understanding of nature can and should be used to advance the material conditions of humanity, and the belief that power and government are there not to serve the rich and powerful but society at large. The combination of these two and their triumph in the market for ideas created a massive synergy that led to the economic sea changes we observe, from industrialization and the growth in physical and human capital to the discovery and mastery of natural forces and resources that were still beyond imagining in 1750. It is a tale that will be told, and retold many times, and surely the arguments I have advanced here will be challenged and questioned by many others. That, in the end, is what illustrates the glory of a well functioning market for ideas.