Culture vs Institutions in the Great Enrichment.

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ABSTRACT

Is there a connection between the Industrial Revolution and the eighteenth century Enlightenment? The Enlightenment was a very broad cultural movement with many moving parts, but the one most relevant to economic history is what is known as the Industrial Enlightenment, a movement that directly advocated institutions that supported and promoted the accumulation and dissemination of technological progress and economic growth. These institutions included those that directly helped incentivize the accumulation of useful knowledge such as patronage and reputation effects, as well as patents, prizes and other rewards to successful inventors. The movement also supported dissemination of knowledge through scholarly societies, publications, and various informal networks. The essay concludes that both culture and the institutions it supported created a fertile ground for the rapid economic growth ignited by the Industrial Revolution.

Keywords:

Technological change

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Innovation

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Introduction: an Institutional Puzzle

Despite some eminent dissenters who have yet to be persuaded, the growing consensus among economic historians today is that "institutions matter" even if they do not necessarily "rule."[1] Following the pioneering work of Douglass North in the 1980s, economists have come to see institutions as the rules of the economic game, determining the incentives and constraints that economic players (individuals, firms and organizations) face, and that they matter to the economic outcomes and performances. Institutions thus matter both to economic performance and to the distribution of resources and power. They determine the extent to which society can overcome opportunistic behavior, reduce transactions costs, and thus make markets work. In addition, they make collective action possible that creates public goods and organizations. These include the enforcement of property rights and contracts and more generally a rule of law and order necessary to facilitate exchange and a more efficient allocation of resources. These arrangements are critical to what is known as Smithian Growth, the kind of economic growth that is driven by deepening and widening of markets, specialization and hence gains from trade, and better allocations of factors.[2]

The historical puzzle is that institutions supporting growth through gains from trade and better allocation of resources do not explain modern economic growth as it emerged during and after the British Industrial Revolution. While specialization and more efficient allocations continued to be an important driver of the rising economic performances of Western countries, the *primum movens* of economic growth increasingly became what eighteenth century writers called "useful knowledge," leading to both process and product innovation and hence to rising productivity known as Schumpeterian Growth. Useful knowledge included what we would call "science" but it was much more than that, such as engineering (Mokyr, Sarid and Van der Beek, 2021; Hanlon, 2022), practical mathematics (Kelly and Ó Gráda, 2021), and industrial chemistry (Clow and Clow, 1952; Christie, 2018). Beyond that, there was a large accumulation of what we

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[1]For a recent critique of institutions as a prime mover in economic history see especially McCloskey (2010, 2016, 2021b) and Clark (2007). The term "institutions rule" is borrowed from Rodrik et al., (2004).

[2]Institutions have also been placed at the center of the literature on the distribution of income and political power (and indirectly on economic power). This aspect of institutions has been discussed at length by Acemoglu, Johnson and Robinson (2005) and Acemoglu and Robinson (2012).

would call today artisanal tacit knowledge. Although such tacit knowledge would not qualify by any stretch as "science", it stood Britain in good service as exemplified by the achievements of relatively poorly educated unscientific "tinkerers" such as George Stephenson, Joseph Bramah, Charles Tennant, and Richard Roberts.

Useful knowledge, both innovation and diffusion, were at the heart of the Industrial Revolution and everything that came after. To summarize the main message of this essay: institutions played a crucial role in the Industrial Revolution, just as they had in Smithian growth in the centuries before. But these were different institutions, encouraging innovation in addition to well-functioning markets and better allocations. Some of them were specifically innovation-friendly, others created a more general environment that made progress possible. But to understand such institutions, we need to examine the beliefs and attitudes that supported them and that were part of the Enlightenment.

Why Europe? The Enlightenment was a European-world phenomenon. To be sure, the deeper roots go back further in time. The technologies that constituted the Industrial Revolution were new, but Europe's advantage in generating them had started before the Industrial Revolution and should be therefore seen as causal and not endogenous to the Industrial Revolution. Whether or not we wish to call it a "Scientific Revolution" or not, in the centuries we associate with the Renaissance and the Baroque eras, Europeans increased their knowledge of the phenomena and regularities that govern the natural world at an accelerating rate, pulling ahead of the rest of the world. Progress continued apace in the decades after the publication of Newton's *Principia* in 1687. On the eve of the Industrial Revolution, Dr. Johnson in his *Rasselas, Prince of Abyssinia* wrote a famous paragraph explaining why Europeans could easily visit Africa and Asia "for trade and conquest" but not the reverse. The imaginary African philosopher replied, "they are more powerful than we, sir, because they are wiser; knowledge will always predominate over ignorance. But why their knowledge is more than ours I know not" (Johnson, 1759, p. 49).

Within Europe there were differences as well. Useful knowledge should have been spread fairly evenly across western Europe, but the capability to deploy it in a profitable way surely was not. The main reason was the sharp inequality in tacit, artisanal knowledge, taught through personal contact and often unmodified. In that area Britain held an advantage that was, for a while, unassailable and secured it the leadership role in technological progress in the first Industrial Revolution. The large literature explaining British precocity has provided a number of reasons that complement one another, among them geography such as the advantages of being an Island and the presence of minerals and coal; institutions such as the growth of the rule of law, constraints on the monarchy, and the norms that supported the existence of social capital and resulted in what Judge Blackstone famous called “a polite and commercial people” (Blackstone, (1765-69), Book III ch. 22; for details, see Kelly, Mokyr, and Ó Gráda, 2014; 2023).

To repeat: this not to say that other factors did not play an important role. But the institutions that supported the growth and diffusion of useful knowledge were crucial. In the absence of continuously expanding knowledge, the other forces that could generate economic growth, including a growing international trade sector and rising labor mobility would have run into diminishing returns and eventually ground to a halt. In a world of purely Smithian growth, there would have been no Industrial Revolution; the growth of prosperity due to the division of labor, regional specialization, more efficient markets, and other elements in Smith’s idea of what drove growth would have mercilessly slowed down and fizzled out and the world would have ended up in the stationary state envisaged by classical economics, driven by the curse of concavity.

While I will be largely concerned with the institutional roots of useful knowledge and technological progress, it should be stressed that the institutional origins of Britain’s Industrial Revolution were larger than just their effect on innovation (Mokyr, 2008). By 1700, Britain’s institutions had developed features that set it apart from much of the rest of Europe. The seminal paper that related political institutions to the Industrial Revolution, published in 1989 by North and Weingast (1989), is well-known and requires little discussion. It established the view that emphasized the Glorious Revolution and the rise of Parliament as the central locus of power in England (later Britain) and the creation of effective constraints on the executive. In their view, these were crucial to secure property rights and the rule of law, and hence were the keys to subsequent economic progress. Parliament became “the place where absolute despotic power, which must in all governments reside somewhere, is entrusted,” as Blackstone noted (1765–69, Book 1, ch. 2, section III). It became what may be called a “meta-institution” that is, an institution that had enough legitimacy to create other institutions.

There were at least three other institutions that set Britain apart and that have been argued to be factors in bringing about economic progress. One was the English Poor Law. Beginning in the 16th century with the dismantlement of Church institutions, the English state gradually displaced the Church and voluntary associations as the main provider of poor relief. The “Old Poor Law” of 1601 formalized this system. In a seminal paper, Solar (1995) suggested a variety of ways in which the Poor Law contributed to British economic development and industrialization. As a form of insurance, he argued, it was relatively free from the usual banes of insurance markets, moral hazard and adverse selection. It may have reduced the need to own land, and encouraged the emergence of wage labor and cottage industries, which were riskier and more volatile sources of income. Thus the Poor Law helped create a rural proletariat force necessary to create the capitalist, market-oriented farming system that made Britain’s agriculture the most productive and efficient in Europe. Solar presented his claim that the security provided by the Old Poor Law fostered economic development as a hypothesis.[3] A second institution that played an important role was the apprenticeship system, which in Britain had been largely taken out of the control of England’s rather weak guilds and was organized more as a market-driven system, with contract enforcement increasingly the responsibility of local authorities and courts (Mokyr, 2019; Wallis, 2024). It has been argued that the effectiveness of its apprenticeship system provided Britain with a high quality skilled artisanal class that was famous across Europe and provided it with the crucial technological prowess and competence to make the key inventions of the Industrial Revolution into a reality.[4] A third advantage was the relative integration of the British economy due an important institutional difference between Britain and its continental competitors: the absence of internal tariff barriers and the high development of coastal shipping (driven by market forces) made regional specialization far more advanced than elsewhere, something that was fully recognized by the Continental nations and eventually

[3]Further arguments for the importance of the Poor Law in economic development of Britain are furnished in Greif and Iyigun (2013) and Greif, Iyigun and Sassoon (2013).

[4]For extensive details on the British artisanal advantage see Kelly, Mokyr, and Ó Gráda (2014, 2023, 2024) and Mokyr (2021).

corrected. But there was more: Britain had developed the institutions to make a privately financed transport infrastructure of highways, canals, and harbors feasible (Szostak, 1991; Bogart, 2011; 2019). At first glance the transportation system would seem to have encouraged Smithian rather than Schumpeterian growth, but as argued in Kelly, Mokyr and Ó Gráda (2023), the integration of markets and the regional specialization it supported may also have been an important factor in the advent of the Industrial Revolution.

Those institutional features clearly help in explaining the Industrial Revolution. They may be seen as necessary but insufficient conditions. All the same, more was needed. Institutions could be seen as the fertile British soils in which the seeds of the Industrial Revolution were planted. However, the Industrial Revolution was not a case of spontaneous generation. The seeds for the many advances in power technology, metals and other materials, chemistry, textiles, food processing, lighting and other areas had to be produced by a system that made innovation happen at a much higher rate and larger scale than ever before, and that created economic modernity as we know it.

In what follows, I will raise the question of which institutional elements were behind the growth of useful knowledge in Europe during the British Industrial Revolution and analyze some of the cultural changes that drove them. This is not an issue on which either North or Acemoglu-Robinson spent much time. Somehow they assumed that if incentives were aligned, property rights were enforced, and a country was ruled by an inclusive government that was neither too anarchic nor too despotic, innovations would flow automatically.[5] Such an assumption is rarely well-supported, much less documented.

What drove the institutional developments that took place before the Industrial Revolution that supported and encouraged the creation of useful knowledge? It is widely agreed that behind institutional change there was cultural change, although scholars recognize that the co-evolution of culture and institutions is subtle, complex, and bidirectional (Alesina and Giuliano, 2015). A simple causal connection between the two is should be eschewed. To avoid any confusions, I will define precisely what I mean by Culture and by Institutions and adopt the definitions I used in Mokyr (2016, pp. 9-10). *Culture* is entirely of the mind: it includes

[5]For a recent restatement in the same spirit, see Aghion, Antonin and Bunel, 2021.

preferences, beliefs, values, that are shared by reasonably large groups in society and passed on with modifications between generations. Because of those modifications, they are the subject of choice as well as drift. *Institutions* are (following North's classic definition) the rules of the game (formal laws, customs, norms and so on), and thus set the incentives (rewards and penalties) for behavior. They are set by society at large and hence are normally given parametrically to each individual much like prices are given in a competitive market. Below I will take a new look at the role that both Culture and Institutions played in the Industrial Revolution and hence in the Great Enrichment.

Cultural drivers of institutional change: the Industrial Enlightenment

It is hard to think of the cultural and institutional changes in Europe in the eighteenth century without coming to grips with one of the most important cultural movements since the invention of monotheism: the Enlightenment. The Industrial Revolution started in Britain at a time when the Enlightenment was arguably at its peak, when the best minds in Europe were writing the works that are still regarded as the most influential sources of Enlightenment thought.[6] The importance of the Enlightenment stands undiminished despite its many critics and enemies. To quote one author — no friend of the Enlightenment — "what is this event that is called the *Aufklärung* and that has determined, at least in part, what we are, what we think, and what we do today?" (Foucault, 1984, p. 21). More recently, Pagden (2013, p. 5) has opined that "no topic of historical debate...has exercised anything like the hold which the Enlightenment does over the ideological divisions of the modern world."

What was the connection between the Enlightenment and the Industrial Revolution? It would seem a coincidence almost beyond belief that two events this momentous, occurring roughly at the same time and the same place, would be unrelated. Moreover, the early days of the Enlightenment predated the Industrial Revolution by many decades, so it seems unlikely to be concerned about reverse causation, i.e., that the Great Enrichment drove the Enlightenment.

[6] Traditionally, economic historians date the Industrial Revolution between 1760 and 1830, though some of the most important breakthroughs, such as steam power, crucible steel making and the use of coke in iron smelting, took place in the first half of the eighteenth century.

That said, the Enlightenment as a whole may be too large a tent and too broad an intellectual movement to be "causal" in this context. After all, for many years historians convinced themselves that the Enlightenment was primarily a French affair and the Industrial Revolution a British one. Neither are true, but this view illustrates the difficulty in drawing a causal link here.

To sharpen the causal connection between the Enlightenment and the Industrial Revolution, I have proposed the concept of an *Industrial Enlightenment*, to denote the specific segment of the Enlightenment most relevant to the Industrial Revolution (Mokyr, 2002). It pertains to a body of thought concerned with applying knowledge of natural phenomena and regularities to production to achieve material progress. It thus excludes much of the philosophical writings of the most celebrated canonical Enlightenment *philosophes* such as Hume, Kant, Montesquieu, and Condorcet). It is deeply connected to the belief in progress that came to life in Europe in the sixteenth and seventeenth centuries (Slack, 2015). Indeed, progress was at the very heart of the agenda of the Industrial Enlightenment. In the area of science and technology, perhaps more than anywhere else, did the majority of thinkers replace "fortune's wheel" (a cyclical view of long-run history) with "time's arrow" — a directional historical trend supporting meliorism (Outram, 1995, p. 124). Progress was at the heart of the Industrial Enlightenment.[7]

There is little evidence of a widespread belief in progress before the early modern age in Europe (Bury, [1920] 1955; Terpstra, 2024). By 1700, however, the idea that material progress had taken place in the past and more of it could and should take place in the future had ripened in large parts of Europe, as much of the useful knowledge of the ancient world was being replaced in a wide range of fields. Most Enlightenment thinkers believed firmly in some kind of historical progress, although their exact notions of what it precisely consisted of differed. Very few thinkers at the time took part in the glum "counter-enlightenment" enunciated for example by Jean-Jacques Rousseau and the Königsberg philosopher Johann Georg Hamann (1730–1788) (Garrard, 2006).

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[7]Even a skeptical and hard-nosed intellectual such as Edward Gibbon could gush in the closing paragraph of Vol. IV of his Rise and Decline that we could "acquiesce in the pleasing conclusion that every age of the world has increased, and still increases, the real wealth, the happiness, the knowledge, and perhaps the virtue, of the human race" because the inestimable gifts of the arts and commerce could never be lost.

The Industrial Enlightenment did more than just hoping for progress. It formulated a practical program as to how to bring it about. Astonishingly, much of this program was implemented as part of the two great political revolutions of the late eighteenth century and the more peaceful institutional reforms elsewhere. To be sure, unavoidable setbacks and misfirings occurred, but material progress continued apace in later centuries even if the term "the enlightenment" seems to have faded for describing what happened after 1815. The age of Enlightenment was, perhaps, not an enlightened age and much of its recommendations did not carry its full load of fruit until the nineteenth century. Yet continuing technological progress based on the accumulation of useful knowledge in the nineteenth century explains why the Industrial Revolution as a cluster of innovations did not fizzle out and became a sustained movement of economic growth.

The "Baconian program," the ideology that formed the backbone of the Industrial Enlightenment, consisted of two components. First, research in fields such as physics, chemistry and botany should *expand* the understanding of the material world and hence useful knowledge. As Boyle and other Baconians insisted, by directing research into natural phenomena that had been of practical interest for a long time, armed with better research equipment and scientific methods, nature could be harnessed to serve people better. The research agenda should thus be directed to areas where there was a high chance of solving practical technological problems—in medicine, manufacturing, shipbuilding, navigation, and so on. Secondly, the *access* to this knowledge should be made as easy and cheap as possible, not only by dissemination but also by organizing and classifying what was known, so as to maximize the chance of it being applied in productive manner.

Hence, the practical program of the Industrial Enlightenment was founded on the firm belief that economic growth would be driven first and foremost by the growth and diffusion of useful knowledge.[8] While most economists still saw Smithian growth as the main source of progress, it was becoming increasingly clear that technology was marching ahead at an ever-faster pace. In sum, the Industrial Enlightenment's agenda was about creating institutions that

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[8]The notion of the Enlightenment as a movement toward the practical improvement of material life through useful knowledge — the essence of modern economic growth — has found its expression in titles of studies such as such as Peter Jones (2016) and earlier in Porter (1982), Cunningham and French, eds. (2006) and Bertucci (2017).

stimulated and incentivized the creation of new useful knowledge, and formed organizations that would help diffuse and disseminate existing knowledge by streamlining and cheapening access to it.

What role was played by what we call today "science" — essentially formal knowledge ("natural philosophy")? In England it was practiced largely by well-educated intellectuals, most of them with a knack for practical questions. Enlightenment writers expressed more hope than certainty about the role of science in bringing about the progress that the *philosophes* were debating. There may be some truth to Outram's assessment that "The intellectual status of science was contested, its institutional organizations often weak and certainly thin on the ground, and the nature of its relations with the economy and with government often tenuous" (Outram, 1995, p. 48), but the Industrial Enlightenment was not just about the situation on the ground, but about what the thinkers were hoping to bring about in the future.[9]

Historically, the exact role of science in the Industrial Revolution has been contested since the 1960s until today.[10] Furthermore, the term "science," as Outram stresses, is something of an anachronism. The French term "science" and the German term "Wissenschaft" meant "knowledge" in general and not just and inquiry into natural phenomena and regularities. The only statement on which there seems to be a consensus is that the glass was partially full in 1750 and had gotten fuller (but far from wholly full) in 1850. Either way, natural philosophy in Britain tended to have a practical side. The vast bulk of important scientists of the eighteenth century were concerned with questions that had the potential to have technological applications, none more so than John T. Desaguliers, Stephen Hales, Joseph Black, William Irvine, and Joseph Priestley. Some professional engineers were scientifically informed, such as John Smeaton or William Strutt. A few industrialists, similarly, had good scientific knowledge or kept close

[9]Joseph Priestley, one of the most articulate and distinguished English proponent of Baconian optimism, felt that "all things (and particularly whatever depends on science) have of late years been in a quicker progress toward perfection than ever... The wisdom of one generation will ever be the folly of the next" (1771, pp. 253, 265). In this rosy view, the ability of people to command and control nature would not only lead to them having a life that was more easy and comfortable, but also mean that they would "grow daily more happy" (ibid., p. 6).

[10]Among the scholars strongly supportive of the importance of science and its impact on the Industrial Revolution are Musson and Robinson (1969), Margaret Jacob (1997, 1998, 2000), Wooton (2015) and Koschnick (2023). Among the early critics were Peter Mathias (1979) and Rupert Hall (1974). More recently, Ó Gráda (2016).

connections with scientists.[11] Furthermore, a market for scientific consultants developed in the eighteenth century.[12] Whether in the end the advice formally trained scientists dispensed was of much use or not, clearly quite a few industrialists thought so. Eighteenth century science still had not cracked many of the most pertinent questions needing answers, and hence failed to have much impact on production techniques in use. Phenomena such as combustion, electricity, chemical reactions, the nature of steel, and much more were just being explored. Once science had made the hoped-for progress, Europe was ready for it and applications followed. The institutional structure inspired by the Industrial Enlightenment thus consisted of a host of organizations and networks, such as scientific societies, masonic lodges, libraries, and informal clubs, whose function was, among others, to disseminate useful knowledge from those who possessed it to those who believed they could use it (Koschnick, 2023). Dissemination of this type was the purpose of what Larry Stewart (1992) has called "public science." For every successful attempt to use scientific insights and methods, there many failures and dis-appointments. But progress was assured in the long term.

While at its base the Industrial Enlightenment was a cultural phenomenon reflecting a belief in material progress and ideas on how to bring it about, it had deep institutional roots. The "associational society" that Peter Clark (2000) has described so well included meetings of formal and informal networks, in which scientific and philosophical lectures and public experiments took place. Peter Clark added (p. ix) that "If a British Enlightenment did exist, then one of its principal engines was the Georgian voluntary society. Fanning out across the English-speaking world, clubs and societies may have served as a vector for new ideas, new values, new kinds of social alignment, and forms of national, regional, and local identity." As Roy Porter (1981, p. 5-8) argued forcefully, the British Enlightenment — far more than elsewhere — was aimed at the

[11]For example, the Manchester cotton spinner George A. Lee, the owner of the first industrial mill to introduce gas lighting, was described by none other than Robert Owen as "one of the most scientific men of his age" (cited by Musson and Robinson, 1969, p. 99). Josiah Wedgwood, of course, was a Fellow of the Royal Society, an amateur geologist, and a close friend of both Priestley and Erasmus Darwin. Thomas Bentley, Wedgwood's partner, was a genuine intellectual who spoke fluent French and Italian and was a founder and trustee of the celebrated Warrington dissenting academy.

[12]Among the most successful of these consultants were the clockmaker John Whitehurst, a member of the Lunar society, and the Cornish applied mathematician Davies Giddy (Gilbert). Whether this activity, while lucrative, actually yielded on average any tangible net benefits to those who hired consultants is no more obvious in the eighteenth century than it is today. For more details, see Mokyr, (2009), pp. 57-59.

solution of practical, material issues. England may not have produced the *Critique of Pure Reason,* he noted, "the real intelligentsia was not chairbound but worked in the market place...English thought was concrete, practical ... the Enlightenment in England was marked by its pragmatism."[13] The interests of British Enlightenment thinkers, unlike many of the great *philosophes* on the Continent, were not primarily in deep political and metaphysical issues, but in practical and pragmatic ones such as pistons, pumps, and pulleys.[14]

It was in these networks that much of the interaction between producers and natural philosophers occurred. For the complementarity between ideas and practice to occur, the practitioners on both sides had to connect. The famed "Lunar Society" and similar famed clubs such as the Manchester Literary and Philosophical Society and its successor in London, the London Chapter Coffee House were only the tip of the iceberg here: less regular (and less high-powered) meetings occurred in private salons, masonic lodges, and provincial societies (Stewart, 1992).

Did it work? Recent research has shown that these networks had a major impact on technological advances and industrialization (Dowey, 2016; Galofré-Vila, 2023). When taken to the data, it turns out that the networks and other organizations designed to disseminate information are clearly capable of explaining the spatial pattern of technological progress as measured (imperfectly) by patents and prizes in industrial exhibitions. Moreover, the estimates that establish a causal connection between such forms of social capital and the Industrial Revolution may tend to underestimate the importance of the networks, because many of them were private and informal, taking the form of informal lectures and meetings in coffeehouses and taverns (Cowan, 2005).

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[13]Elsewhere he added (Porter, 2000, p. 15) that "British pragmatism was more than mere worldliness: it embodied a philosophy of expediency, a dedication to the art, science and duty of living well in the here and now."

[14]One may wonder what the roots of this difference were. One possible explanation is that in the late seventeenth century, Britain created a form of government that may not have been democratic, but all the same was widely regarded as functional and legitimate as the central power was Parliament and not the monarchy. Unlike French *philosophes*, most British intellectuals did not strongly object to their regime as a whole even if they often took issue with many of its decisions and policies.

Why did this matter?[15] Historically, one of the sources of technological stagnation had been the social divide between those who knew things (*savants*) and those who made things (*fabricants*).[16] The importance of this connection for technological progress was first pointed out by the sociologist Edward Zilsel (1942), who emphasized the importance of the relationship between artisans and intellectuals in early modern Europe for subsequent economic development. To construct pipelines or *passerelles* as Hilaire-Pérez (2000) has called them, through which those two groups could communicate, was at the core of the Industrial Enlightenment movement. As noted above, the communications ran in both directions: practical people with specific technical problems to solve could access and absorb whatever best-practice knowledge had to offer — which, of course, at most times was rather little. At the same time, the needs of crafts and manufactures to solve specific problems could influence the research agenda of the scientists. The famous close connections between James Watt and his Scottish academic friends John Robison and Joseph Black are a prime example. So was the growing demand for scientifically informed consultants by progressive industrialists (for more details, see Mokyr, 2009a, pp. 57-59).

The Industrial Enlightenment, interestingly enough, was to a considerable extent a provincial affair. London, of course, remained the cultural center of the country where a large number of skilled artisans catered to the local market. But in provincial towns such as Manchester, Liverpool, Newcastle, and Leeds, we find, as J.H. Plumb (1972, p. 23) memorably put it, "knots of enlightened men with a passionate regard for empirical knowledge, secular in their intellectual attitudes, although often muddled, uncertain and tentative, with ... rational and irrational beliefs combined in the same man." The networks that made the Industrial Enlightenment so effective can be described as small world networks (a network where the typical number of hops between two randomly chosen nodes is small in some sense, e.g., grows proportionally to the logarithm of the number of nodes in the network). This means that people who mattered were mostly connected in little localized cliques with a few connections between

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[15]Some of the following is adapted from Mokyr (2005).

[16]In one of his most perceptive essays, Needham (1969, p. 27) pointed out that in Imperial China 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.'"

these nodes. Between 1750 and 1850 the number of these internode connections rose as communications improved, but even in its earlier times they were effective enough.[17] Better roads and coastal ships, better carriages, and improved postal services were at the core of the ever more effective connections between local nodes.

Such a bilateral interchange between formal science and technology seems natural to us in the twenty-first century. In eighteenth-century Europe, however, such interactions developed slowly, impeded by social inertia and snobbery. Yet in the longer run they proved as irresistible because their role in promoting the continuing progress of technology was recognized by producers. Precisely because the British Enlightenment was more focused on material issues, it was supportive of the growth of communications between natural philosophers and the more progressive and open-minded industrialists of the time (Porter, 1981, 2000).

For information networks to be efficient, trust was essential.[18] Members of associations and scientific societies exchanging knowledge had to trust one another, but often knowledge came from strangers. It was therefore essential that agents had the cultural propensity to trust their sources and assume a high probability that the information they accessed was correct. In that regard it is important to stress that a long tradition of universalistic values, in which people felt that unrelated persons and even strangers were trustworthy, went back to the Middle Ages and the disappearance of extended kinship as the chief form of social organization. A substantial modern literature has found evidence that societies that are less founded on extended kinship tend to be more trusting and more able to cooperate with strangers (Henrich, 2020; Enke, 2019 and 2023; Schulz, 2022). As argued in detail in Greif, Mokyr and Tabellini (2024), the prevalence of more universalistic values and trustful social norms was a likely consequence of the European Marriage Pattern that was established in the Middle Ages. The weakening of the extended family made the kind of organizations dedicated to the transfer of knowledge among

[17]During the eighteenth century British mail services improved significantly. In their original form, almost all letters sent within England had to go through London. The idea of cutting out London (which seems obvious enough to us) occurred to Ralph Allen (1693-1764) a Cornwall postal employee and one of the unsung successful entrepreneurs of the first half of the eighteenth century. By the time of Allen's death in 1764, most of England and Wales received mail daily through his “byway post” (Headrick, 2000, p. 187).

[18]For a detailed discussion of the role of trust and social capital in the Industrial Revolution, see Sunderland (2007).

strangers more prevalent and more effective.[19] In that sense, the Industrial Enlightenment had an unexpected and certainly unintended ancestry.

These networks, then, reduced access costs. The lowering of access costs, to be sure, was driven in part by technological shocks — above all the printing press and better postal services — but it had a critical institutional component as well. The rules of the scientific community and open science increased trust, as investigators shown to be charlatans or plagiarists at least in theory suffered costly damage to their reputations. Access costs did not only matter because of the ability of innovators to access the relevant scientific theories and experimental data that learned people assembled. New knowledge builds upon existing knowledge, tweaking and recombining it into new forms, but in order to do so, it needed to know what was already there. The intellectuals who subscribed to the ideas of the Industrial Enlightenment recognized this need and created the means to access knowledge through a range of publications that ordered and organized existing knowledge in an accessible way.

Such publications needed two things to be effective. One was an ordering of the contents in a handy way, such as alphabetization. The other was to make it accessible through libraries or cheap editions. The books published through the inspiration of the Industrial Enlightenment were part of one might call the codification project. It consisted of the description and depiction of what had hitherto been mostly tacit knowledge, the kind of knowledge possessed by craftsmen and mechanics, passed on to their apprentices but less easily to others. These objectives were achieved most famously in the *Grande Encyclopédie*, widely regarded as one of the paradigmatic documents of the Enlightenment. Robertson (2021, p. 419) notes that many artisanal skills previously guarded from outsiders were now placed in the public realm. d'Alembert and Diderot's masterpiece was a "landmark in the diffusion and demystification of knowledge." What he fails to add was that in addition to the encyclopedia, assorted compendia and technical dictionaries "of all arts and sciences," were published all over Europe, even if they less

[19]As argued at length in Greif, Mokyr and Tabellini (2024, chapter 9), many of the social organizations that emerged in the Middle Ages indirectly and through often winding paths, led to the kind of organizations that drove the Industrial Enlightenment. An example is the Republic of Letters, a loose network of intellectuals, who were not related, but cooperated through a common objective to expand useful knowledge. Indirectly, such organizations were made possible through the weakening of extended families and the rise of corporations and associations such as guilds, universities, scientific societies and the like in medieval times.

ambitious and encompassing than d'Alembert and Diderot's grand design (Headrick, 2000, pp. 142-172). In what is now a classic paper, Squicciarini and Voigtlaender (2015) showed how access to the encyclopedia was correlated with technological progress and the rise of modern industries.

Another way of organizing useful knowledge in an accessible way was to publish specialized books describing the state of the art techniques in various industries. The most impressive of these projects was no doubt the over thirteen thousand pages of the 80 volumes of the *Descriptions des Arts et Métiers* compiled by the French academy before the Revolution — in Gillispie's (1980, p. 344) judgment the largest body of technological literature ever produced. Many other specialized books on individual industries appeared, especially in France. While Britain had a comparative advantage in tacit knowledge and the "knacks" of the trade, acquired through informal and personal channels such as apprenticeship and personal knowledge, the European Continent seems to have had a comparative advantage in formal and codified knowledge. The most impressive and best-organized textbook of pre-Lavoisier chemistry was P.J. Macquer's encyclopedic *Dictionnaire de Chimie* published in 1766 and translated into English in 1771 by the chemist James Keir. The same was true, surprisingly, for technological knowledge. The most detailed and richest technical book on coal and collieries was written by a French physician, Jean-François C. Morand (1768-79). While England had the most extensive copper-smelting industry in eighteenth century Europe, economic historians depend on continental sources for its description (Harris, 1992, p. 22). The English engineered and produced; the French wrote about it. Both nations had been part and parcel of the Industrial Enlightenment, and both realized that knowledge was the key to economic progress; but there were nuances in how they were going to carry out this program.

Finally, access to useful knowledge was furthered by the British patent system, discussed in more detail below. As Dutton (1984, p. 22) remarked, full and detailed disclosure of the technical details of an invention was the price that society charged for patent protection. Once these details were deposited in the office of chancery, they were accessible, albeit at a cost. Bottomley (2014, pp. 177-201) has shown that arguments that inventors submitted deliberately misleading specifications and that the documents were hard and costly to access are overblown. Many details were published in cheap magazines such as *The Mechanics Magazine* published between 1823 and 1858. He provides numerous examples of various individuals consulting the documents that otherwise would have been almost impossible to access. In short, intellectual property rights in new technological knowledge meant that there was a sharp trade-off between patents and secrecy, and the many inventors who made use of the patent office contributed to the lowering of access costs. That, too, was part and parcel of the Industrial Enlightenment.

High-powered and Low-Powered Incentives.[20]

As has been long understood, the creation of new knowledge is underincentivized. Knowledge is non-rivalrous, often non-excludable (or costly to exclude), and creates major externalities (since knowledge builds on previous knowledge). As a result it is difficult to design any incentives — either high-powered or low-powered — that adequately encourage and incentivize inventors and scientists. While a few inventors gained fame even before 1600 (one thinks of Hero of Alexandria, Gutenberg, and William Lee) it is hard to think of many examples of pre-1750 inventors who became rich thanks to their ingenuity even if it contributed materially to economic performance.[21] On the eve of the Industrial Revolution, after centuries of gradual institutional change something of a bifurcation in the way contributions to useful knowledge had emerged. Propositional knowledge was rewarded largely through reputation effects and other low-powered incentives; prescriptive knowledge could be rewarded directly though patents or other financial rewards.

The European Enlightenment — and especially British Enlightenment — believed in the sanctity of property rights. Of course, almost all societies had some concept of property rights. However, the idea of property rights in ideas and knowledge — IPR's — was a uniquely Western idea; no such notion can be found for instance in Chinese culture. By the late eighteenth century, European writers realized not only that patents were a moral institution — rightly rewarding a successful inventor and recognizing a moral claim on what was deemed to be

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[20]Some of the following is adapted from Mokyr (2009b).

[21]It is telling that nothing is known about the identity of some of the other striking inventions of the Middle Ages such as the mechanical weight-driven clock, eye glasses, fire arms and the introduction of windmills.

property by priority — but that it actually stimulated and encouraged innovation and thus economic development.[22] Modern economics has found the idea attractive, as it provided an easy and intuitively powerful connection between institutions and the technological progress that drove modern economic growth (North 1981, pp. 164-65; Aghion et al., 2021, p. 37). England, after all, had a patent system that predated the Industrial Revolution by over a hundred years. and as this institutional foundation safely predated the Industrial Revolution, it effectively rules out reverse causation. Moreover, as Adam Smith also believed in a famous passage in his *Lectures on Jurisprudence* (1759, p. 83), it rewarded inventors more or less in proportion to the contribution of their invention, and thus created a high-powered incentive to engage in innovative activity. Or so it seemed.

The problem is that a closer look at the British patent system leads to serious reservations regarding its effect on the Industrial Revolution. The net effect of patents on technological change remains in serious dispute till the present day (Boldrin and Levine, 2008), all the more so for the eighteenth century. In a few cases patents have been argued to have actually blocked innovation by the threat of litigation. Perhaps more damaging, the number of actual patents filed before 1750 was small and took off with the Industrial Revolution.[23] It is hard to assign it a major causal role. Moreover, patents constituted a small fraction (about one in six) of all important inventions. This was demonstrated in devastating detail by Moser (2005, 2021), and while one can question the exact percentages involved, anecdotal evidence strongly supports her findings. For a few inventors, the system worked and they were able to secure a temporary monopoly on a lucrative technological breakthrough. But for many of the most important inventions of the era, the patent system was either not utilized at all or failed to protect the

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[22]Goethe famously wrote that the "clever Englishman" was able to turn ideas into property and sighed that "no wonder they are in every way ahead of us" (cited by Klemm, 1964, p. 173). In 1795 Chief Justice James Eyre of the court of common pleas observed that many patents existed for new methods of manufactures that were "beyond all calculation important to commercial activity . . . and in my apprehension it is strictly agreeable to the spirit and meaning of the Statute" (cited by Bottomley, 2014, p. 152).

[23]Around 1768, inventors began to use specialized patent agents, which streamlined the clumsy and slow application process and clearly was a factor in the sudden take-off of the number of patents after 1760 or so (Bottomley, 2014, pp. 65-73).

inventor.[24] Until 1851 patenting in Britain was expensive beyond the reach of most middle-class inventors coming from the artisanal class, and legal protection from infringements through the courts was weak and unreliable.[25] Additional incentives stimulating technological progress had to come from elsewhere.

In some ways the market system found other ways to reward technological pioneers, above all through the "first-mover advantages" as was famously the case with Richard Arkwright. In other cases they tried to secure a monopoly by keeping a crucial ingredient secret — if this was feasible. In other cases, the political system stepped in directly, with Parliament voting substantial pensions or awards for people whose innovations had been deemed especially useful (most famously the large awards, totaling £ 30,000, awarded to Edward Jenner, the inventor of the smallpox vaccination). Prestigious prizes to successful scientists whose work was likely to have practical consequences were established, The Copley Medal, established by the Royal Society in 1736, was a powerful signaling devices and many winners were artisans and engineers. Among them were some of best inventors of the Industrial Revolution, such as the leading engineer John Smeaton and the instrument maker Jesse Ramsden (Bektas and Crosland, 1992). The Rumford medal for Majors discoveries in heat and light (the first of which was awarded to Rumford himself in 1800) was a similar token of respect to innovators. Membership in the Royal Society remained a coveted distinction even if the Society showed some signs of intellectual atrophy in the eighteenth century.[26] In a few cases, inventors could shield their

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[24]Moreover, if it was the patent system that accounted for Britain's leadership, one might wonder why other economies were not more successful earlier. Britain's patent system and its policies encouraging invention were not unique: the Netherlands did have a system of patents awarded by both the Estates General and the provincial estates from the late 1580s on, awarding a peak number of 119 patents in the 1620s. Yet in the eighteenth century, the number of patents dwindled into insignificance (Davids, 2008, pp. 400-416). Ancien régime France, too, had a system of rewarding inventors even if it worked quite differently from the English patent system (Hilaire-Pérez, 2000).

[25]Because of their dogmatic opposition to monopolies of any kind, judges often decided against patentees. Consequently, patentees who felt their patents were infringed rarely sued: between 1770 and 1850 only 257 patent cases came before the courts out of 11,962 patents granted (Dutton, 1984, p. 71). Bottomley (2014, pp. 79-85) has revised Dutton's numbers, but even so, less than 2.5 percent of cases were litigated before 1830.

[26]In a few cases, specific prizes were promised for inventors who would solve concrete problems that were regarded as especially important, such as the problem of longitude at sea. While the standard tale of the British Board of Longitude, which was formally in charge of administering the funds, has been radically revised in modern times (Howes, 2022) the basic fact remains that two well-known scientists, William Whiston and Humphrey Ditton, petitioned Parliament to establish the Board, realizing that exerting efforts to solve required both a reward and

monopoly through secrecy, though it seems unlikely that many techniques and formulas could be protected for long from imitation and reverse engineering.

Inventors were driven by other motives as well. Many of the great engineers wanted to become known as ingenious and creative individuals so as to secure commissions from manufacturers and local authorities based on reputations. Some inventors who had been trained in formal schools had absorbed the culture of open science and felt that it was immoral to exclude others from knowledge, which was after all non-rivalrous.[27] Clearly, of course, not all of them were pure altruists: many if not most cared deeply about their reputations among their peers, about membership in the Royal Society, medals, knighthoods and other reputation-signaling devices.[28] Institutions, then, encouraged the growth of useful knowledge, but the incentive structure driving innovation was more complex than the simple-minded greed driving efforts that non-economists attribute to the beliefs of economists (for more details, see Mokyr, 2018).

The same holds for the patent system. Human behavior and psychology played just as much a role as income-maximization. Entrepreneurship and invention — and a fortiori patenting in England during the Industrial Revolution — are like unfair gambles or lotteries. What makes such lotteries work is that a few spectacular and well-publicized successes led others to believe that their odds were better than they really were. Its very existence drove many would-be inventors toward exerting efforts in the hope of securing the kind of riches that James Watt and

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financial support during the (rather tedious and lengthy) research effort.

[27]Michael Faraday only took out one patent in his life and one that had nothing to do with his main line of research, namely a better chimney for the use of lighthouses (which he made over to his brother). His mentor, Humphry Davy, refused to take out a patent for the famous "miner's friend" lamp he invented and claimed repeatedly to be "philosophically" opposed to patents (Ruston, 2019).

[28]Economists have long argued that especially in the upper tail of the human capital distribution — the one that matters most the economic development — agents are driven by more than material incentives. As pointed out by Kreps (1997), the distinctions between intrinsic motivation and status incentives can be fairly tricky. Kreps notes that in most employment situations (and that covers the bulk of the citizens of the Republic of Letters) it is hard to detect intrinsic motivation. He notes that "what is called intrinsic motivation may be (at least in part) the worker's response to fuzzy extrinsic motivators, such as fear of discharge, censure by fellow employees, or even the desire for coworkers' esteem." Here "coworkers' esteem" should be interpreted as "the opinion of other scientists and intellectuals." Reputations, then, led to memberships, appointments, knighthoods, and was of course also desirable for their own sake.

Charles Tennant had gained from the patent system. This is all the more powerful precisely because by definition all inventions are in some qualitative dimension different from one another (unlike lottery tickets) and a function of the ability of the inventor. It is therefore easier for "gamblers" on the patent system to persuade themselves that the conditional odds that underlie decisions in this activity may be systematically higher than the unconditional ones. In other words, would-be inventors overestimated their abilities and thus their chances for a successful patent as Adam Smith famously pointed out (Smith, [1776] 1976, p. 120). The expected rate of return on inventive activity for the *entire* population of inventors was in all likelihood negative, but because of a salient upper tail, the ex ante incentives were powerful (Nye, 1991). And they were what mattered. All the same — and this is an important point if we are to understand the Industrial Revolution — for society as a whole, the benefits were substantial, since the social returns of inventive activity exceeded the private return by a large factor. Hence anything that can inflate the ex ante perception of private returns to get it a bit closer to the social returns will encourage invention and is thus socially beneficial. It is this mechanism that best supports Bottomley's belief that the patent system in Britain "did indeed encourage the development and diffusion of technology during the Industrial Revolution" (Bottomley, 2014, p. 174).

All in all, the Industrial Enlightenment became permeated with the notion that new prescriptive knowledge should be seen as "property" and that inventors "owned" the rights to it even though they were required to divulge the details of their invention. Over time, thus, the eighteenth century turned the concept of a "patent" from a monopoly and a privilege (and thus a form of rent-seeking) into a property right that increased efficiency, reflecting the ideas of the Industrial Enlightenment.[29] The idea of a patent was perfectly consonant with the Industrial Enlightenment — a patent had to be potentially useful for practical purposes to be granted at all, but would only become financially valuable if it met the market test.

Following their respective revolutions, both the United States and Republican France established patent offices within a year from one another in 1790-91. By securing this property,

[29]Biagioli (2006, p. 1136) has argued that it was that "it was the introduction of patent specifications that made that contract [between patentee and the public] politically defensible by distancing it from the 'odious monopolies' of the ancien régime."

it was believed that technological creativity was incentivized and hence was encouraged.[30] In short, it was a mechanism supporting material progress. As John Stuart Mill (1848, p. 933) summed it up, the patent system clearly dominated any reward system run by the state. All the same, it was widely understood to be a second-best solution. Enlightenment writers overwhelmingly opposed monopolies, and a patent was a monopoly. There was an intuitive sense that knowledge should be free-access because anything that limited access to useful knowledge was obviously in contradiction with the other objective of easy access. It was also realized that patents were used strategically, for example to block research by non-patentees in some directions, and thus actually slowed down innovation (as the classic examples of Thomas Savery's patent blocking Thomas Newcomen from patenting his steam engine and James Watt blocking high pressure engines attest).[31]

The Society of Arts, one of the most paradigmatic organizations reflecting the values of the Industrial Enlightenment founded in 1754, awarded medals and small prizes to inventors — provided the invention had not been patented (Howes, 2020).[32] Over time, the Society gave a preference to projects that for one reason or another could not be patented or made profitable. It emphasized inventions that saved lives, made workplaces safer, prevented traffic accidents, replace child-labor in chimney sweeping and the like (Howes, 2020, pp. 73-81). Moreover, through its meetings and its library and other facilities, it became a clearing house for useful knowledge, a repository for information on technology (id., p. 84). Much like the patent system

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[30]James Madison wrote that "The utility of the clause will scarcely be questioned... The right to useful inventions seems with equal reason to belong to the inventors. The public good fully coincides in both cases with the claims of the individuals." (Madison, 1788).

[31]Charles Babbage, never one to mince words, denounced the patent law as a system that deprived the inventor of the fruits of his genius and put the most productive citizens of society in a position of "legalized banditti." It was a "fraudulent lottery which gives its blanks to genius and its prizes to knaves" (Babbage, 1830, pp. 333, 321). The objections were not so much against the system in general as much as against the way the law was written and carried out in Britain, especially the high cost "system of vicious and fraudulent legislation" which deprived the inventor of the fruits of his genius and that even the granting of a patent was "almost wholly illusory" till the patent had been sustained by a court of law, at an even higher cost (id., p. 334).

[32]William Shipley, its founder, viewed its purpose as follows: "Whereas the Riches, Honour, Strength and Prosperity of a Nation depend in a great Measure on Knowledge and Improvement of useful Arts, Manufactures, Etc. ... several [persons], being fully sensible that due Encouragements and Rewards are greatly conducive to excite a Spirit of Emulation and Industry have resolved to form [the Society of Arts] for such Productions, Inventions or Improvements as shall tend to the employing of the Poor and the Increase of Trade" (cited by Mokyr, 2009, p. 52).

discussed above, it managed to combine in one organization both incentives and diffusion of useful knowledge. It embodied the essence of the Industrial Enlightenment.

Incentivizing and rewarding propositional knowledge was more difficult as it could not be patented. This kind of knowledge shares many of the features of the commons (Ostrom and Hess, 2007). Much like a commons, knowledge is a shared resource, but one that is produced in the system and has a positive opportunity cost. Unless people somehow can be charged for its use, at first blush no one has any financial incentive to produce it. The putative "tragedy of the commons" suggests that any system of knowledge production would flounder on the non-excludability of knowledge. And yet, just as the commons do not always become a tragedy but can be managed by a community, knowledge production can be and was properly incentivized if the correct institutions emerged. The cultural background to the emergence of these institutions was the Industrial Enlightenment.

To see how this came about, note that the Industrial Enlightenment was in large part the product and logical continuation of the Republic of Letters, the earliest signals of which can be traced to the late fifteenth century (Mokyr, 2016). The Republic of Letters was an information network that served to diffuse knowledge among intellectuals, and in the process it created reputations of the best and the brightest among learned men and women. These reputations were of course valuable in and of themselves for intellectuals craving peer recognition and respect, but they were also strongly correlated with coveted royal and aristocratic patronage, which meant both enhanced social status and economic security (and in a few cases political influence).

Patronage and fame were of course not the sole driver of the growth of propositional knowledge in the era of the Industrial Revolution. Science had become respectable, virtuous, something that rich burghers or gentlemen such as Anthonie van Leeuwenhoeck, Henry Cavendish, and Antoine Lavoisier kept themselves busy with.[33] Others, however, still depended on reputations to win gainful employment, especially when universities declined them

[33]Cavendish seems to have been remarkably agnostic about his reputation as a scientist. The discoverer of hydrogen, and in some views "without peer in eighteenth century English natural philosophy...the first after Newton to possess mathematical and experimental talents at all comparable to Newton's" (McCormmach, 2008, p. 159), he published a number of things, but many of his most important findings remained unpublished and were discovered only many years after his death.

positions.[34] In short, the concept of "open science" proposed by Dasgupta and David (1994; see also David, 2008), in which priority rights (that is, the credit given to the person who claimed to be the first to have discovered a natural phenomenon or regularity) operated much like property rights in physical assets, flourished in the eighteenth century and operated in harmony with the Industrial Enlightenment. Superstar intellectuals, inventors, and scientists achieved what we would call today celebrity status, sometimes deserved, sometimes not. But the enormous reputation enjoyed by Isaac Newton could not but stimulate countless ambitious and talented mathematicians and physicists "to be like Ike." A century after Newton, Edward Jenner's fame (and resulting financial reward) must have done the same for medical researchers.

Incentives to scientific research came in many flavors. One of the great insights was that it turned out to be fairly cheap to incentivize innovative intellectuals to add to propositional knowledge. International fame and peer recognition were and still are major drivers of intellectual excellence and all that was needed was a few inexpensive signals that broadcast eminence. The idea was an old one: Marcus Aurelius endowed some chairs in philosophy in the second century AD (Frede, 2012). The practice was revived in early modern Europe, with the emergence of the Republic of Letters. A key figure in this regard was Lady Margaret Beaufort, the mother of the first Tudor king Henry VII, who established the Lady Margaret's professorship of divinity at the University of Cambridge in 1502 and a lectureship in divinity at Oxford. A few years earlier the first Regius Professorship had been endowed in Aberdeen, and Henry VIII established the first ones in England among others in Law, Greek and Medicine. The Lucasian chair in mathematics at Cambridge was the first privately-endowed chair, per Henry Lucas's will, in 1663. Isaac Newton was the second holder of the chair and held it for 33 years. It is still considered to be one of the most prestigious academic chairs in the world. Membership in the Royal Society remained a desirable honor, with "FRS" becoming a badge of accomplishment. Such distinctions became more prevalent in the eighteenth century as part of the program to encourage the progress of useful knowledge by rewarding persons who were regarded as having

[34] An example is the career of Leonard Euler, refused a professorship by the University of Basel, who found a patronage position at the Russian Imperial Academy and later at the Berlin Academy at the invitation of King Frederick II.

added substantially to useful knowledge such as the abovementioned Copley medal. Other European nations followed similar practices (Hilaire-Pérez, 2000).

Furthermore, the interest in promoting useful knowledge supported the idea of natural philosophers and great engineers as role models and high social-status people, whom young and ambitious persons would want to imitate. The full acceptance of this value took a long time to reach maturity, but at least two giants in British history, Newton and Watt, managed to achieve exactly that (Fara 2002; MacLeod, 2007). On the Continent things were moving along the same lines. In early eighteenth-century France, the new science was especially valued and became part of high society and a new political culture in which a powerful alliance was created between the *savants* of the Republic of Letters and the royal administration (Shank, 2008, p. 88).[35] The Dutch physician Herman Boerhaave was so famous in his time that Peter the Great sat in on his classes and Voltaire and Linnaeus traveled to Leyden to meet him.[36] The great Pierre-Simon Laplace himself was elected to the French *Académie* at age 24 and eventually was made a count of the Empire in 1806 and a marquis in 1817, as well as appointed to a rather unsuccessful stint as Minister of Interior affairs in 1799.[37] The effective allocation of talent and human capital in the extreme upper tail of the distribution of talent was sensitive to such signals. It was those kinds of institutions that provided the incentives for modern science to evolve eventually into the fuel that powered the engines of progress.

One driver of scientific progress that is underestimated is sheer curiosity. Whether curiosity is more or less hard-wired in humans is hard to know, but clearly culture has the capability to encourage or discourage it.[38] In early medieval Christianity, curiosity was broadly

[35]Shank explains that royal administrators saw academics as a model and a catalyst for bringing about a wider transformation of French society, but the social boundary between savants and royal officeholders was often quite blurry.

[36]A possibly apocryphal story has it that a letter sent from China by a Mandarin, addressed simply to 'the illustrious doctor Boerhaave, physician in Europe,' reached him without delay.

[37]One way of raising the social status of science and scientists was to appoint them to high political positions — something that Napoleon, in many ways a adherent of the Industrial Enlightenment, excelled in. In addition to Laplace, he appointed the chemists Antoine-Francois de Fourcroy as Minister of Public Instruction and Jean-Antoine Chaptal as Minister of the Interior, as well as making the mathematician Gaspard Monge a count in 1808 and appointing him to a key position in the Senate.

[38]Some of the following is adapted from Mokyr (2018).

condemned as unbecoming to a good Christian, and regarded as an attempt to peek into God's domain. St Bernard of Clairvaux (1090-1153), an influential monastic reformer, promoted curiosity to one of the seven deadly sins as a subspecies of "lust" (Daston, 1995, p. 393). Two centuries later, however, Thomas Aquinas made some fine distinctions between the kinds of knowledge that were virtuous to pursue and those that were not.[39] The aversion to new knowledge for its own sake was thus already weakening in the later middle ages, but it was still powerful and can still be found in Jean Gerson and Erasmus (Robertson, 2021, p. 44; Rummel and MacPhail, 2021).

In any case, early modern Europe experienced a cultural transformation that turned curiosity into a virtue rather than a sin, especially for the elites. Renaissance courts and academies proudly paraded their curiosity and saw the display of new knowledge as a symbol of the superiority and power of the ruling classes. This new attitude was particularly manifest in the proto-museums known as "curiosity cabinets," which displayed exotic animal- and plant specimens and antiques (Eamon, 1994, pp. 223-224).[40] The intellectual father of the Industrial Enlightenment, Francis Bacon, insolently warned his readers in *The Great Instauration* not to fall into the error of thinking "that the inquisition of nature is in any part interdicted or forbidden" and cited with approval Proverbs 25:2 that stated that "it is the honor of God to conceal a thing and the honor of kings to investigate them" (my translation from the Hebrew) (Bacon [1620], 1999, pp. 74-75). While Bacon still warned that the "true end of knowledge" should not be "for the pleasure of the mind," research of any kind was turned into a virtuous

[39] Aquinas (1947, questions 166-167) viewed the intrinsically-motivated search for knowledge favorably within limits. As long as the philosophers do not seek truth "to assail the faith" and not study "to know the truth above the capacity of his own intelligence, since by so doing men easily fall into error," he was willing to allow a certain level of curiosity. He distinguished between "*studiositas*" and "*curiositas*," the former being a virtue, the latter a vice under certain circumstances.

[40]One of the most striking of these collection was the one established in Rome by the polymath Athanasius Kircher, a German-born Jesuit (1602-1680) whose museum of curiosities was the most famous in Europe and contained a range of archaeological, technological, and scientific objects. Kircher was a person of almost infinite curiosity, "a one-man intellectual clearing house for cultural and scientific information" as the *Encyclopedia Britannica* described him. His 44 books covered a bewildering range: geography, astronomy, mathematics, language, medicine, ancient history, and music.

activity.[41] Renaissance Europe experienced the emergence of a class of “virtuosi” — upper class gentleman devoted to study of arts and sciences. While much of their work was amateurish and dilettantish, their activities raised the prestige of intellectual discourse and they provided a constituency and readership for the people who did the heavy lifting in research. The virtuosi provided much-needed social respectability to those who contemplated engaging in intellectual endeavors and they helped turned curiosity from vice to virtue.

By the early years of the Industrial Enlightenment, the moral acceptability of research driven by curiosity had become relatively uncontroversial and the social status of great scientists kept rising.[42] Many noted scientists and inventors came from the very top of a highly hierarchical society. Robert Boyle was one of the wealthiest men in England, and Antoine Lavoisier a wealthy tax official in France. The abovementioned reclusive Henry Cavendish (the grandson of the Duke of Devonshire), or the Scottish experimentalist Archibald Cochrane, the Earl of Dundonald (who worked on a chemical process to make coal tar and ruined himself financially in the process) were equally driven by curiosity. Ferdinando de Medici II, grand duke of Florence and Galileo's patron (1610-1670), is credited with the invention of a substantially improved thermometer in the mid seventeenth century. Whereas financial gain, social status, and economic security were important incentives in the creation of scientific knowledge, intrinsic motivation and curiosity cannot be discounted. Some of the great scientists in the Scientific Revolution and research in the age of Enlightenment were driven by it.

Finally, it is worth reiterating that incentives for expanding knowledge can be both positive (a reward) or negative (penalizing people for heretical ideas, disrespectful of sacrosanct ancient wisdom). The well-known tales of Galileo and Copernicus illustrate the risks that scholars proposing radical new ideas were taking. Less well-known but perhaps more damaging

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[41]Thomas Hobbes defined curiosity as the desire to know the causes of things, and noted that "such as is in no living creature but Man; so that Man is distinguished, not onely by his Reason; but also by this singular Passion from other Animals; in whom the appetite of food, and other pleasures of Sense, by praedominance, take away the care of knowing causes...is a Lust of the mind, that by a perseverance of delight in the continuall and indefatigable generation of Knowledge, exceedeth the short vehemence of any carnall Pleasure" (Hobbes, ([1651], 1929, p. 44). Clearly he realized that research was fun — an intrinsic motivation indeed.

[42]As Lorraine Daston phrases it, “moralists continued to thunder away against such frivolous and potentially dangerous interests... but the decibel level of their complaints suggests that by the late seventeenth century they were on the defensive” (Daston, 2005, p. 37).

was the persecution of Jan Baptist van Helmont, a Brussels-born chemist and the founder of pneumatic chemistry, who was condemned for "perverting nature by ascribing to it all magic and diabolic art" and interrogated by the inquisition, as was Giambattista della Porta, an Italian polymath and inventor, whose Neapolitan scientific society known as the *Accademia dei Segreti* founded in 1560 was disbanded on orders of the Inquisition. We will never know with precision how many aspiring young scientists were discouraged or frightened into abandoning their careers on account of these persecutions. But it has been shown that the counter-reformation seriously damaged scientific work, especially south of the Alps as well as the number of scientists in countries strongly affected by the actions of the Inquisition (Cabello, 2023).

The Enlightenment movement as a whole was profoundly committed to tolerance, freedom of speech and association, and had nothing but scorn for censorship. Led by such luminaries as Locke and Voltaire, Enlightenment intellectuals struggled to be rid of any kind of ideological persecution or censorship of new ideas, and this included useful knowledge. Controversial writers such as La Mettrie and Helvétius could still get in trouble for provocative ideas (though rarely scientific discoveries), and in Britain, where censorship had been abolished, political rebels and excessively disrespectful authors could be sued for obscene or seditious libel. Such legal suppression of thought that strayed too far from what the authorities deemed acceptable was still fairly common in Enlightenment Europe, but legal sanctions against scientists and physicians — no matter how outrageous their arguments were thought to be— are hard to find. The Industrial Enlightenment was part of a greater movement toward toleration and freedom of expression that rid Europe of a serious obstacle to progress and by and large eliminated negative incentives. The first amendment to the US constitution was a concrete example of the influence that these intellectuals had on eighteenth century institutions. Again, then we can see how culture affected a set of specific institutions that turned out eventually to be crucial to the economic development of Western Europe.

Conclusions

Institutions, in the sense of setting incentives and creating both opportunities and the rewards for taking advantage of them, have become a major theme in economic history. Yet oddly enough, with some exceptions, they have not been systematically explored in trying to understand why the Industrial Revolution occurred at all and why it took place first in Britain.[43] What is needed above all, is an explanation of the impact of institutions on innovation and technological creativity in an eighteenth-century context. In other words, to understand the Industrial Revolution, we need to lay bare why innovation occurred at all, as most societies that existed before 1750 were far less innovative than eighteenth-century Britain. An examination of the various institutional aspects shows, first and foremost, that political institutions and the other institutions that determined the distribution of power and authority in Britain were important, but so were private-order institutions. What is now needed above all are measurement and testing of the impact of institutions as much as possible; in this debate an ounce of data is worth more than a pound of theory.[44]

The deeper question, and one that the neo-institutional literature has struggled to answer, is why some economies have institutions that are more conducive to technological progress than others and therefore become technological leaders, if only for limited periods. Are institutions themselves endogenous to economic and material factors as Marxian orthodoxy maintained? Or are they wholly determined by what people value and believe, as recently argued by McCloskey (2021b)? I have made a similar argument at considerable length in Mokyr (2016).[45] It seems reasonable to argue that rather than one "driving" the other, they co-evolve, affecting one another but also both affected by exogenous shocks and events. History, however, is rich with examples in which institutions were not in any way chosen by societies, but imposed through raw political and military power.

The exact ways and channels in which culture affects institutions is a topic that still awaits full incorporation in economic history, and will be a project large enough to keep an entire generation of scholars busy (Alesina and Giuliano, 2015). But proof of the notion that any

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[43]For earlier surveys see Kapás (2012) and Mokyr (2008, 2021).

[44]A pioneering attempt to test some of the alternative hypotheses is Dowey (2016) and Galofré-Vila (2023); see also Kelly et al., (2023).

[45]There is a somewhat pedantic debate on whether the word "culture" is an appropriate term. McCloskey (2021b) feels that "'culture' is merely the vague way in which economists talk when they have not actually taken on board the exact and gigantic literature about ideas, myths, stories, rhetoric, ideology, metaphors, ceremonies, and the like since the Greeks, the Talmudists, or the Sanskrit grammarians." Basically, however, the standard definitions of culture as the "unions of the sets of shared beliefs and values in a society" as proposed by Boyd and Richerson (1985, p. 2) in their pioneering work on cultural evolution seems perfectly adequate for the purpose at hand.

single cultural factor is either necessary or sufficient to create the kinds of institutions needed for technological progress seems so far elusive. Moreover, the dynamics of institutional change are still poorly understood. In many cases institutions were created for one reason and led to unintended consequences. Neither the Poor Law of 1601 nor the Patent Office of 1624 were created by people with an Industrial Revolution in mind. In other cases, fairly small events led to contingent institutional outcomes with far-reaching implications for innovation and economic progress.

Moreover, discrepancies can persist between what people want and like and the kind of institutions they actually experience. After all, political revolutions can occur quite abruptly, and it seems implausible that culture, which is quite sticky and resistant to rapid change, would change pari passu. For instance, was Russian culture completely turned upside down between 1985 and 1991 with the demise of Marxism-Leninism? Or did Iranian culture and devoutness change dramatically between 1978 and 1980 when a theocratic Islamic state took over? Closer to the topic at hand here, McCloskey (2010) argued that an ideology of liberalism and individual freedom led to "a liberal releasing of opportunity" and was the key to growth. In fact, however, eighteenth century Britain was hardly the liberal (in the classical sense) laissez faire society it was to become in the second quarter of the nineteenth century. It was a highly regulated and protectionist state in which rent-seeking and mercantilist ideas constrained and distorted many markets. Moreover, non-liberal institutions can, under the right kind of government, generate innovation and technological progress, even if in the very long run they are perhaps less sustainable and welfare-enhancing as free-market pluralist societies.

Furthermore, anyone arguing for the primacy of culture over institutions owes us — no mean requirement — some kind of theory of where ideas come from and why they become prevalent, that is, why they triumph in the market place for ideas. To complicate matters further: institutions in turn can successfully bring about cultural change by successful propaganda and steering education and social conditioning in one direction or another.[46] In the absence of a more general theory explaining the coevolution of culture and institutions, we have to be satisfied with

[46]Of the many examples that illustrate this point, a striking one is the success of Nazi educational policies to install antisemitic ideas in German youngsters, a culture that survived into the post-war period. See Voigtländer and Voth (2015).

the more modest project of finding how cultural phenomena such as the Industrial Enlightenment led to the institutions that helped bring about the Great Enrichment.

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