The Great Synergy: the European Enlightenment as a factor in Modern Economic growth

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Introduction

In this paper I propose to summarize and extend an argument made in a number of other papers (Mokyr 2005a, 2005b, 2005c). The issue at stake is a variant of the *European Miracle* question. Despite the resentment in certain circles against the questions concerning the "Rise of the West" as a valid historical inquiry, the question will not go away, because it is good history even if it is politically controversial. It is perhaps ironic that the problem is now more central to economists and so-called "world-historians" rather than the rest of the History profession. Indeed, to quote Robert Lucas (1988), the more we look at the problem of modern growth the less we can think of anything else that matters.

The consensus is that modern economic growth was started by the British Industrial Revolution. As is well-known, during the Industrial Revolution itself growth was in fact fairly modest, but the sudden take-off of GDP per capita after 1825 or thereabouts could not have happened without a long period of laying the foundations that made it possible.[1] The transformation was tantamount to a "phase transition," a sea change in the mechanics of economic growth, with technological progress gradually coming to dominate the process, accounting for its novel features. But what were these foundations, exactly? It is this issue that this paper seeks to address.

Before doing so, two central points have to be understood. The first is that events like a cluster of macroinventions such as happened in the first decades of the Industrial Revolution are not altogether unique in history, neither in Europe nor elsewhere. Moreover, growth, as Jones (1988) and many others have noted, was not a new phenomenon in nineteenth-century Europe either. Many regions or groups had managed over the centuries to accumulate wealth, to produce surpluses beyond subsistence, as works of art, architecture, and science amply indicate. Yet none of these processes had persistence; growth was always checked and eventually fizzled out. Often it was reversed, and societies declined and in a few cases entirely lost their former wealth. The telling characteristic of modern growth is its sustainability, indeed its inextinguishability. Despite the best efforts of European rulers, growth was not stopped in the twentieth century and indeed on average accelerated and brought much of Europe unimagined riches by the closing decades of the twentieth

[1] For the most recent estimates of growth during the Industrial Revolution, see Mokyr (2004); Harley (1998).

century. When does this phase transition really happen? The critical watershed was perhaps during the decades after Waterloo. It is quite conceivable that growth would have fizzled out after the inventions in cotton, steam, and iron of the late eighteenth century, and that would have been it. But that is *not* what happened. Indeed, the closing decades of the nineteenth century were a period of unprecedented technological advances, preparing much of the ground of twentieth century growth and destruction (Smil, 2005).

The second point is that the idea that the Industrial Revolution was "British" and that Europe was just a "follower" seems overstated and in some sense wrong. Some areas of Europe such as Flanders, Alsace, and Switzerland were able to follow Britain fairly quickly, and while sense of inadequacy among contemporary Continental Europeans in the first half of the nineteenth century when comparing their industrial achievements to Britain can be perceived, modern economic historians have been more cautious about this Continental "backwardness." It needs to take into account the high toll that the political turmoil between 1789 and 1815 had on the economies of Continental Europe. Although these upheavals can be regarded as the price that the Continent had to pay to "catch up," the gap between Britain and the Continent was never in the order of magnitude of the gap between the West and, say, China or Africa.

What, then, was behind this transformation? Historians have engaged the issue now for a century, and little of a consensus has emerged. Two significant recent contributions, Landes (1997) and Pomeranz (2000) have divided the causal factors between culture and geography. Earlier, Jones (1981) provided a veritable smorgasbord of explanations, including the ingenious idea of the European "States System" which likened the fragmented political power in Europe to a competitive market, limiting the damage that rulers could inflict on their economies. Others have focused on "Western Science" as the crucial variable (e.g., Rostow, 1975; Cohen, 2004; Lipsey, Carlaw and Bekar, 2005). Still others blamed European imperialism, itself due to accident, and dismissed the entire event as epiphenomenal.[2] These explanations have been vigorously criticized and vigorously defended.

It is odd that in that literature the European Enlightenment plays such a minor role. In recent decades,

[2]This is true for the more moderate scholars in the so-called California school such as Wong (1997), Pomeranz (2000), and Goldstone (2002) as well as for the more extreme proponents such as Blaut (2000) . Goldstone (2002, p. 330) feels that to even repeat such beliefs that have been "abandoned by virtually all historians and sociologists" [with the minor exception of such obscure figures as David Landes and Jared Diamond] is "embarrassing or seemingly absurd."

the European Enlightenment has not fared well in the views of historians. The Enlightenment has been held responsible for the twentieth-century horrors by Adorno and Horkheimer and their modern-day postmodern epigones such as John Gray. One of the oddest phenomena in modern historiography, indeed, are the vitriolic and nasty attacks on the Enlightenment, which perversely is being blamed for modern-day Barbarism but never credited for bringing about modern-day prosperity.[3] I would argue the contrary: it would seem to be a natural candidate in explaining the great divergence. After all, its timing took place approximately in the century before the beginning of modern growth in Europe, and it was clearly a Western phenomenon, its success more or less confined to the countries that by 1914 constituted the so-called convergence club of rich industrialized countries. Yet economic historians must have felt uncomfortable with the Enlightenment as an explanatory factor, perhaps because it is a relatively amorphous and poorly defined intellectual movement, perhaps because the Enlightenment was believed to be primarily "French" whereas the Industrial Revolution was "British," and perhaps because the connections between beliefs and intellectual conventions and economic events are poorly understood, Keynes's protestations to the contrary notwithstanding.[4] Yet cultural beliefs are becoming increasingly an object of interest to economists, because they tend to be the result of persuasion and diffusion, and because they can be understood as "conventions" and "norms" underlying changes in social institutions and behavior.

In what follows, I will argue that the Enlightenment played an important, perhaps crucial, role in the emergence of modern economic growth. This is not to denigrate other factors altogether. The cotton industry, one of the mainstays of the Industrial Revolution, could not emerge without access to the sources of raw cotton, so international trade cannot be disregarded altogether. Monetary and financial elements in the story are obscured, as are demographic and other factors. But the Enlightenment had two major effects that I should

[3]Horkheimer and Adorno, 1971; Gray, 1995. This revulsion has deep philosophical roots in the works of Nietzsche and Heidegger, but the usefulness of the critique to historians interested in economic progress is doubtful. Even left-wing historians are embarrassed by notions that the Enlightenment inevitably led in some way to male-domination, imperialism, totalitarianism, environmental degradation, and exploitation. Eric Hobsbawm notes with some disdain that this literature describes the Enlightenment as "anything from superficial and intellectually naive to a conspiracy of dead white men in periwigs to provide the intellectual foundation for Western Imperialism." See Hobsbawm, 1997, pp. 253-65.

[4]The idea that the Enlightenment was somehow a French affair in which Britain played at best a supportive role is devastated by Porter (2000). For detailed data, see Mokyr, 2005c. On cultural beliefs, see Greif, 1994, 2005. Keynes's famous remark is to be found in Keynes (1936), pp.383-84: "the power of vested interests is vastly exaggerated compared with the gradual encroachment of ideas .... soon or late, it is ideas, not vested interests, which are dangerous for good or evil."

like to emphasize. First, it transformed the motivation and dynamics of technological progress. Second, it altered the institutional mechanism through which technological change affected the economy. These two formed a synergy that was the very foundation of the "European Miracle."

The Enlightenment and the Growth of Useful Knowledge

The European Enlightenment was a multifaceted phenomenon, much of it concerned with the natural rights of human, concepts of religious and racial tolerance, political freedom, legal reform and much else. At the deepest level, the common denominator was the belief in the possibility and desirability of human progress and perfectability through reason and knowledge. The material aspect of this belief followed in the footsteps of Francis Bacon's idea of understanding nature in order to control her. Useful knowledge became the buzzword of the eighteenth century. This term should not be associated simply with either "science" or "technology."[5] It meant the combination of different kinds of knowledge supporting one another. Not all of it was abstract science: the taxonomic work of Linnaeus and the descriptive writings of Arthur Young increased useful knowledge just as much as the abstract mathematics of Laplace and the experiments of Priestley and Lavoisier.[6]

The eighteenth century marked both an acceleration of the pace of research and a growing bias toward subject matter that, at least in principle, had some practical value. Indeed, Peter Burke (2000, p. 44) has argued that the eighteenth century saw the rise of "the idea of research" and the sense that this knowledge could contribute to economic and social reform. The change in the pace of progress of knowledge after 1680 is closely related to the triumph of Newtonianism in the first half of the eighteenth century. The achievement of Newton did more than anything else to establish the prestige of formal science in the world of learning

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[5]This point has been well-made by Inkster (2004), whose analysis parallels what follows in certain respects. Inkster proposes the term URK ("Useful and Reliable Knowledge"), which is much like the term proposed by Kuznets who preferred "testable." In my view *reliability* is an important characteristic of useful knowledge, but it seems less crucial than *tightness*, that is, the confidence and consensualness with which certain knowledge is held to be "true."

[6]Linnaeus's belief that skillful naturalists could transform farming was widely shared and inspired the establishment of agricultural societies and farm improvement organizations throughout Europe. One source of confirmation of the belief in the possibility of economic progress may have been perceptions of agricultural progress. As Gascoigne (1994, p. 185) 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."

(Jacob and Stewart, 2004). It was widely believed that the growth of useful knowledge would open the doors of prosperity. But it was also clear that this growth could only be carried out collectively, through a "division of labor" in which specialization and expertization were carried out at level far higher than before.[7] The way useful knowledge increased in the eighteenth century was a far cry from the processes of R&D (corporate and government) of today. It might be better to say that much of it was by way of exploration and discovery, trial and error processes minimally informed by an understanding of the natural processes at work, inspired tinkering, and a great deal of serendipity and good fortune, albeit favored by prepared and eager minds. Over the eighteenth century these search processes became more systematic, careful, and rigorous. New methodologies were invented, such as the great engineer John Smeaton's development of the method of parameter variation through experimentation, which is a systematic way of making local improvements in a technique without necessarily understanding the underlying science (Cardwell, 1994, p. 195).

The hopes for a quick technological payoff to scientific research were, on the whole, disappointed in the eighteenth century. The "customary chasm" between science and the mundane details of production could not be closed in a few decades or even a century.[8] One can, of course, find examples in which scientific insights did enrich the knowledge of key actors in the Industrial Revolution. Dexterity and mechanical intuition were in many cases complementary to certain critical pieces of scientific knowledge which guided and inspired the work. The scientific milieu of Glasgow in which James Watt lived was contributed to his technical abilities. He maintained direct contact with the Scottish scientists Joseph Black and John Robison, and as Dickinson and Jenkins note in their memorial volume, "one can only say that Black gave, Robison gave, and Watt received."[9] The introduction of chlorine bleaching and the solution of the longitude problem

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[7]Joseph Priestley, the great chemist, noted that "If, by this means, one art or science should grow too large for an easy comprehension in a moderate space of time, a commodious subdivision will be made. Thus all knowledge will be subdivided and extended, and knowledge as Lord Bacon observes, being power, the human powers will be increased ... men will make their situation in this world abundantly more easy and comfortable." (Priestley, 1768, p. 7). Adam Smith, in the "Early Draft" to his Wealth of Nations (1978, pp. 569-72) believed that 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.

[8]The term is due to Floris Cohen (2004, p. 118) who adds that in the seventeenth century useful applications of the new insights of science kept eluding its proponents.

[9]Dickinson and Jenkins (1927), p. 16. Hills (1989, p. 53) explains that Black's theory of latent heat helped Watt compute the optimal amount of water to be injected without cooling the cylinder too much. More interesting, however, was his reliance on William Cullen's finding that in a vacuum water would boil at much lower, even tepid temperatures, releasing steam that would ruin the vacuum in a cylinder. In some sense that piece of propositional knowledge was essential to his realization that he needed a

depended, to some extent, on advances in science and formal hydraulics contributed to advances in water power (Reynolds, 1983). Yet when all is said and done it is clear that much of the progress we associate with the first Industrial Revolution needed little more than a mechanics that Galileo knew, and that the innovation in manufacturing and agriculture before 1800 advanced without science providing them with indispensable inputs. William Cullen, the leading chemist of the mid-eighteenth century, was retained by Scottish manufacturers to help them solve a variety or problems. His self-serving prediction that chemical theory would yield the principles that would direct innovations in the practical arts remained, in the words of the leading expert on eighteenth-century chemistry, "more in the nature of a promissory note than a cashed-in achievement" (Golinski, 1992, p. 29). Manufacturers needed to know why colors faded, why certain fabrics took dyes more readily than others, and so on, but as late as 1790 best-practice chemistry was incapable of helping them much (Keyser, 1990, p. 222). In medicine, in metallurgy, and in agriculture, to name a few areas, the situation before 1800 was not different. The world may have been more messy and complex than the early and hopeful proponents of the Baconian program realized, as Cohen (2004, p. 123) has suggested. In addition, scientists did not know enough and lacked the tools to learn quickly. Tacit artisanal knowledge, such as mechanical dexterity, intuition, experience-driven insights, and similar resources drove much of the early inventive processes, although dismissing the input of science altogether is unwarranted.

And yet, the belief that somehow useful knowledge was supposed to be key to economic development not only did not fade as a consequence of such disappointments, it kept expanding on both sides of the channel. The Baconian "program" was built on the belief that the expansion of useful knowledge would solve technological problems and that the dissemination of existing knowledge to more and more people would have substantial efficiency gains. These two notions formed the core of Denis Diderot's beliefs and his admiration for Francis Bacon — the first philosopher to clearly lay out a technological program for economic expansion — permeates his writing as well as that of many other eighteenth-century *philosophes* and scientists. In Britain, of course, this belief was not only widespread, but formed the explicit motive for the

separate condenser.

foundation of organizations and societies that were designed to advance it.[10]

Progress was limited simply by what people knew. The age of Enlightenment, for instance, never had a good concept of what "heat" really was, its chemistry was, until the 1780s, anchored in phlogiston theory, and its understanding of biology and disease, despite some significant local advances, had progressed little beyond Galen. Yet it was also readily recognized that very intelligent people, schooled in experimental science and mathematics, could make substantive contributions to technology even if they were not always quite sure why and how new techniques worked. Thus mathematicians were asked — and at times succeeded in solving mundane and practical problems.[11] Many scientists were concerned with the properties of steel: René Reaumur and Tobern Bergman were concerned with its properties, recognizing its economic significance, and three of France's most learned men published in 1786 a learned paper establishing once and for all the differences between wrought iron, cast iron, and steel — even if the full effects of this insight were still decades in the future.[12]

Men of science applied themselves to invention. Most of them applied the notions of "open science" to their invention, and placed the knowledge in the public realm. Benjamin Franklin, Humphry Davy, Joseph Priestley, and Benjamin Thompson (Count Rumford), four of the leading scientists of the later decades of the Age of Enlightenment, made numerous inventions and yet refused to take out any patents, arguing that their efforts were made for the benefit of mankind and not for private profit. Such hybrid careers became very common in the nineteenth century. Michael Faraday, besides his pathbreaking research on electricity, worked on various problems in materials, especially steel and glass (Bowers, 1991). Eda Kranakis (1992) emphasizes the work of the French engineer and mathematician Claude-Louis Navier (1785-1836), who, among others,

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[10]William Shipley's credo is summed up in his "plan" for the establishment of the Society of Arts (1754): "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." (Allan, 1979, p. 192).

[11]MacLaurin provided an ingenious solution (1735) to the problem of measuring the quantity of molasses in irregularly shaped barrels by the use of classical geometry. Not only did he solve the rather difficult mathematical problem with uncommon elegance, he also provided simple formulas, tables, and algorithms for the customs officers, that were used for many years. See Grabiner, 1998, pp. 139-168. Leonhard Euler, the greatest mathematician of the century, was concerned with ship design, lenses, the buckling of beams, and (with his less famous son Johann) contributed a great deal to hydraulics.

[12]The three were Alexandre Vandermonde, Claude Berthollet, and Gaspar Monge, who jointly published their "Mémoire sur le fer," under the influence of the new Chemistry of their master Antoine Lavoisier.

used the recently developed Fourier analysis to analyze the vibration in suspension bridges, and did pioneering work in fluid dynamics for which he is still famous. His work, and that of other *polytechniciens*, was highly abstract and mathematical, and of long-term rather than immediate applicability. Not so that of Lord Kelvin, a prolific inventor, who owned seventy patents in electromagnetic telegraphy, marine navigation equipment, and electric instruments.

One of the key innovations of this Industrial Enlightenment, as I have called it (Mokyr, 2002, ch. 2) is the building of bridges between the sphere of knowledge and that of production, between *savants* and *fabricants*. Diderot expressed this need strongly in his celebrated essay on "Art" in his Encyclopedia. This idea dates from the earliest stages of the Enlightenment.[13] Whether or not this led to technological progress already in the age of the Renaissance, as argued by Zilsel (1942), the movement was slow and gradual. William Thompson, Count Rumford, still sighed wistfully in 1799 that "there are no two classes of men in society that are more distinct, or that are more separated from each other by a more marked line, than philosophers and those who are engaged in arts and manufactures" and that this prevented "all connection and intercourse between them." He expressed hope that the Royal Institution he helped found in 1799 would "facilitate and consolidate" the union between science and art and to direct "their united efforts to the improvement of agriculture, manufactures, and commerce, and to the increase of domestic comfort" (See Thompson (1876), pp. 743-45).

In Enlightenment Europe, a class of people emerged that made it their business to build such bridges, by arbitrating as it were between the spheres of natural philosophy and useful arts. Among those I might mention as especially interesting the career of William Nicholson, the founder and editor of the first truly scientific journal, namely *Journal of Natural Philosophy, Chemistry, and the Arts* (more generally known at the time as *Nicholson's Journal*), which commenced publication in 1797.[14] It published the works of most of

[13]Thomas Sprat expressed it in the 1660s when he wrote that no New Atlantis (Bacon's ideal scientific community) was possible unless "Mechanick Labourers shall have Philosophical heads; or the Philosophers shall have Mechanical hands." See Sprat, 1702, p. 397. In its early days, the Royal Society invested heavily in the study of crafts and technology and commissioned a History of Trades, but this effort in the end failed. Cf. Hunter, 1989.

[14]Nicholson was also a patent agent, representing other inventors. Around 1800 he ran a "scientific establishment for pupils" on London's Soho square. The school's advertisement announced that "this institution affords a degree of practical knowledge of the sciences which is seldom acquired in the early part of life," and promised to deliver weekly lectures on natural philosophy and chemistry "illustrated by frequent exhibition and explanations of the tools, processes and operations of the useful arts and common

the leading scientists of the time, and functioned much like today's *Nature* or *Science*, that is, to announce important discoveries in short communications.[15] Or consider the career of Joseph Banks, one of the most distinguished and respected botanists of his time, whose life was more or less coincident with the Industrial Revolution. Wealthy and politically-well connected, Banks was a co-founder (with Rumford) of the Royal Institution in 1799, a friend and scientific consultant to George III, and president of the Royal Society for forty-two years. While not a pioneering scientist himself, for most of his life Banks labored tirelessly to help bring about the social and economic improvement the Baconian program advocated, corresponded with many people, supported every innovative branch of manufacturing and agriculture, and was the dominant political figure in Britain's world of science for much of his life.[16] He was every inch an Enlightenment figure, devoting his time and wealth to advance learning and to use that learning to create wealth, "an awfully English *philosophe*" in Roy Porter's (2000, p. 149) memorable phrase. Their counterparts in France were such figures as Henri-Louis Duhamel de Monceau, a noted *agronome* and the chief editor of the massive *Descriptions des Arts et Métiers*, and François Rozier (1734- 1793), another *agronome* and scientific entrepreneur, "a clergyman whose vocation was the enlightenment" in Gillispie's succinct characterization, publisher of the *Observations sur la Physique, sur l'Histoire Naturelle, et sure les Arts*, widely regarded as the first independent periodical to be concerned wholly with advances in cutting-edge science (Bourde, 1967, pp. 253-76, 313-68; Gillispie, 1980, p. 338).

The connection between the sphere of learning and the sphere of production has always been a sensitive spot in the history of economic growth. In the Classical World, there seems a deep consensus about this weakness. Similarly in China, 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, 1969, p. 27).

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operations of society."

[15]In it, leading scientists including John Dalton, Berzelius, Davy, Rumford, and George Cayley communicated their findings and opinions. Yet it also contained essays on highly practical matters, such as an "Easy Way of churning Butter" or a "Description of a new Lamp upon M. Argand's Principle."

[16]Among his close friends were the agricultural improvers John Sinclair and Arthur Young as well as two pillars of the Industrial Revolution, Matthew Boulton and Josiah Wedgwood. He was associated among others with the Society for the Arts, before taking over the Royal Society, which he ruled with an iron if benign hand (Drayton, 2000, ch. 4; Gascoigne, 1994, passim).

Narrowing this gap was perhaps the crowning achievement of the Industrial Enlightenment. Part of the contact between the two spheres took place through books and periodicals, and part of it through direct contact and transfer of knowledge through teaching, imitation, and espionage. The document most widely associated with the Enlightenment, Diderot and d'Alembert's *Encyclopédie*, contained numerous articles on technical matters, lavishly illustrated by highly skilled artists who, in most cases, were experts in their fields.[17] To be sure, in some ways the Encyclopedia was a conservative document, and the readership of the many encylopedias that came out in Europe in the eighteenth century was varied. Most readers, as Darnton (1979) has argued, were probably not in a position to find much direct use for these essays, but the useful knowledge contained in it doubtlessly seeped to persons for whom just knowing what was possible must have been significant. As Arthur Young (1772, p. v), himself an assiduous collector of facts, remarked, "before a thing can be *improved* it must be *known*, hence the utility of those publications that abound in fact either in the offer of new or the elucidation of old ones." It might be easy to dismiss this remark as self-serving, and it is no doubt exaggerated. The limitations in expressing technical matters in language and diagrams were no-doubt severe, even if they differed from area to area. They may have been most serious in the coal-using industry where tacit knowledge of the correct temperature and the little tricks in operating furnaces were still largely tacit (Epstein, 2004).[18]

The eighteenth century, however, also witnessed the improvement of the codification of formerly tacit knowledge. Part of it was simply the improvement of the language of technology: mathematical symbols, standardized measures, more universal scales and notation all added a great deal to the ease of communication. Post-Lavoisier chemical nomenclature proposed by the Swedish chemist Berzelius in 1813, after some hesitation, was agreed upon. When new measures were needed, they were proposed and accepted. Thus, as is well known, James Watt proposed in 1784 the total amount of energy necessary to raise 33,000

[17]Pannabecker (1996, 1998) points out that the plates in the Encyclopédie were designed by the highly skilled Louis-Jacques Goussier who eventually became a machine designer at the Conservatoire des arts et métiers in Paris. They were meant to popularize the rational systematization of the mechanical arts to facilitate technological progress.

[18]John R. Harris (2001, pp. 219-21) has been even more skeptical of the importance of science relative to "tacit" skills and 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.

pounds one foot in one minute as the fundamental unit of work, the horsepower.[19] Visual means of communication, above all diagrams and models, were vastly improved.[20] In addition, between 1768 and 1780 the French mathematician Gaspard Monge developed descriptive geometry (Alder, 1997, pp. 136–46), which made graphical presentations of buildings and machine design mathematically rigorous.[21] When human presence was required, travel became faster and more comfortable during the eighteenth century. The idea of the traveling expert or consultant was exploited by Boulton and Watt, whose patent-based monopoly on steam power extended to consulting on energy and mechanics. John Smeaton was perhaps the greatest consultant of all, founding the society of civil engineers, but others followed his example.[22]

Knowledge was also transferred through personal contacts and lectures. Early in the eighteenth century many of those lectures were informal and ad hoc, in pubs and coffeehouses.[23] In the years after 1750,

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[19]Less well-known but equally important is the work of Thomas Young (1773–1829), whose modulus of elasticity (1807) measured the resistance of materials under stress in terms of the pull in pounds that it would take to stretch a bar to double its original length. There were even some attempts to quantify precisely the amount of physical work one man could be expected to do in a day (Ferguson, 1971; Lindqvist, 1990).

[20]The illustrations accompanying the *Encyclopédie* and the eighty volumes of the *Descriptions des Arts et Métiers* (1761–88) approached technical mastery. The eighteenth century witnessed a great deal of progress in "technical representation," and by the middle of the eighteenth century technical draftsmanship was being taught systematically (Daumas and Garanger, 1969, p. 249). Alder (1998, p. 513) distinguishes between three levels of mechanical drawing in pre-revolutionary France: the thousands of workshops where experienced artisans taught free-hand drawing to their apprentices; state-sponsored schools in which drawing teachers taught basic geometry; and the advanced engineering schools in which mechanical drawing was taught by mathematicians.

[21]Monge's technique essentially solved the problem of reducing three-dimensional entities to two dimensions while at the same time depicting the relationships between the parts constituting the shape and configuration of the entity. In Alder's words, "It marks a first step toward understanding how the way things are made has been transformed by the way they are represented" (1997, p. 140).

[22]The clock- and instrument maker John Whitehurst, a charter member of the Lunar Society, consulted for every major industrial undertaking in Derbyshire, where his skills is pneumatics, mechanics, and hydraulics were in great demand; Joseph Priestley worked as a paid consultant for his fellow "lunatics" Wedgwood and Boulton. See Elliott, 2000, p. 83. Schofield, 1963, pp. 22, 201. Another striking example is the emergence of so-called coal viewers who advised coal mine owners on the optimal location and structure of coal mines, the use of equipment, and similar specific issues.

[23]Of the itinerant lecturers, the most famous was John T. Desaguliers. Desaguliers, a leading proponent of Newton with an international reputation (he lectured in the Netherlands) received a royal pension of £ 70 per annum as well as a variety of patents, fees, and prizes. *His Course of Mechanical and Experimental Philosophy* (1724) was based on his hugely popular lectures on science and technology."entertained his provincial listeners with combinations of scientific subjects and Providence and the Millennium." Other British lecturers of note were William Whiston, one of Newton's most distinguished proponents and successor at Cambridge, James Jurin, master of the Newcastle Grammar School, gave courses catering to the local gentlemen concerned with collieries and lead-mines. Peter Shaw, a chemist and physician, the instrument maker Benjamin Martin, Stephen Demainbray who lectured both in France and England and later became Superintendent of the King's Observatory at Kew, and the Rev. Richard Watson at Cambridge whose lectures on Chemistry in the 1760s were so successful that he drew a patronage of £ 100 for his impoverished chair See Stewart (1992), *passim*. In France the premier lecturer and scientific celebrity of his time was Abbé Jean-Antoine Nollet, whose fame rests on early public experiments with electricity (he once passed an electrical charge from a Leyden jar through a row of Carthusian monks more than a mile long). Nollet also trained and encouraged a number of his disciples as lecturers, as well as some

many of those informal meeting-places crystallized into more formal organizations and societies, some of them with official imprimaturs. Of those, the Lunar Society of Birmingham is the best documented (Schofield, 1963, Uglow, 2002), but the Chapter Coffeehouse in London was equally successful as a clearinghouse for useful knowledge (Levere and Turner, 2002). Other organizations were more formal. One such was the Society of Arts, founded in 1754, which encouraged invention by awarding prizes, publicizing new ideas, and facilitating communication between those who possessed useful knowledge and those who could use it. The Royal Institution, founded by Count Rumford and Joseph Banks in 1799, provided public lectures on scientific and technological topics. Its stated purpose in its charter summarizes what the Industrial Enlightenment was about: it was established for "diffusing the knowledge, and facilitating the general introduction, of useful mechanical inventions and improvements; and for teaching, by courses of philosophical lectures and experiments, the application of science to the common purposes of life."[24]

The role of formal educational institutions and human capital in this story is quite different than the standard stories told for the twentieth century. While the Scottish universities did play an active role in the growth of useful knowledge in Britain, the English universities were a more minor factor, although some of the scorn heaped on Oxbridge by contemporaries and historians is exaggerated. The most dynamic element in the English education system were the dissenting academies, which taught experimental science, mathematics, and botany among other subjects.[25] These institutions reached only a thin elite, though apparently that was enough. In general, the idea that the role of universities was to create *new* knowledge rather than transmit existing knowledge to young generations took a long time to ripen. The belief that the Industrial Revolution in its early stages required mass education and literacy has long been abandoned. The British apprenticeship system with the educational institutions mentioned was more than enough to supply

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of the most celebrated scientists of his age, such as Lavoisier and Monge. Similarly, Guillaume-François Rouelle's lectures on chemistry in the Jardin du roi drew an audience that included Rousseau, Diderot and even Lavoisier himself (Stewart, 2004). In Napoleonic France, the "best scientific minds of the day" were lecturing to the public about steam engines, and it became common to regard some scientific training as a natural prelude for entrepreneurial activity (Jacob, 2004).

[24]The lectures given by Humphry Davy were so popular that the carriages that brought his audience to hear him so clogged up Albermarle Street in London that it was turned into the first one-way street of the City.

[25] Among those, Warrington Academy was one of the best, and the great chemist Joseph Priestley taught there for a while, though surprisingly he was made to teach history, grammar, and rhetoric (Schofield, 1963, p. 195).

it with the skills and craftsmanship it needed. The Industrial Revolution was an elite phenomenon: not, of course, just a handful of heroic inventors as Victorian writers in the Smiles tradition would have it, but a few tens of thousands of clever and dexterous mechanics and skilled craftsmen who could read blueprints, knew the properties of the materials they used, built parts according to specification within reasonable tolerance, and had the experience to understand friction, torque, resistance, and similar concepts. For the rest of the labor force, education and literacy may not have mattered much and Britain's had no advantage in it.

The Enlightenment and Institutional Progress

Economists have lately realized what economic historians have known all along, namely that "good institutions" are essential to successful economic growth. In recent years a genuine avalanche of empirical work has pointed to the centrality of property rights, incentives to innovation, the absence of arbitrary rule, and effective contract enforcement, to name but a few institutional elements often mentioned.[26] Yet these studies tend to exploit cross-sectional variation and do not bother much as to how Europe "acquired" these good institutions.

North (1981, p. 166) noted that "the most convincing explanation for the Industrial Revolution as an acceleration in the rate of innovation is one ... in which a combination of better specified and enforced property rights and increasingly efficient and expanding markets directed resources into new channels... more was involved than simply removing restrictions on the mobility of capital and labor— important as those changes were. Private and parliamentary enclosures in agriculture, the Statute of Monopolies establishing a patent law, and the immense development of a body of common law to better specify and enforce contracts are also part of the story." In subsequent work, North and Weingast (1989) dated this institutional change to the British Glorious Revolution of 1688 and the subsequent reforms.

Regardless of the details of the timing, which has been criticized effectively, the Northian view of the Industrial Revolution raises further doubts that go beyond specific tests. Perhaps the deepest one is that there is now abundant evidence that eighteenth-century China was much as North describes, a large integrated

[26]Examples of the literature are Rodrik (2004), Rodrik, Subramanian, and Trebbi (2002), Acemoglu, Johnson and Robinson (2002). A convenient summary is provided in Helpman (2004).

economy, heavily commercialized, entrepreneurial, competitive, with good property rights, law and order, contract enforcement and a government that taxed relatively lightly. If innovation was entirely endogenous to institutional and commercial development, the argument needs to explain China. Even within Europe, however, the argument seems incomplete. Britain's formal law enforcement system was woefully incomplete: it did not even have a police force until deep into the nineteenth century, and its patent system expensive and notoriously hard to enforce. Moreover, what is really needed is an explanation of the success of the West, not specifically Britain. After all, by 1914 in the "convergence club" Britain was at best a *primus inter pares*. France, Germany, and the smaller European countries all were part of the modern growth process. What explains these European institutions and where did they come from?

One way to understand the process is to focus on. The economic significance of the political and institutional reforms of the late eighteenth and early nineteenth centuries has not been fully realized in part because of the undue focus on the *security* of property rights without much attention to the exact *content* of these property rights. It overlooks the fact that *ancien régime* Europe was overgrown with secure and well-enforced local privileges, tax exemptions, monopolies, exclusionary rights, regulations, entry barriers, freedom of occupation, and similar arrangements that hampered markets, impeded technological progress, and threatened economic growth wherever it was attempted. In other words, what needed to be done was the elimination of *bad* rights and contracts.

Mercantilism, the organizing principle of the *ancien régime* economy, was based on the assumption that economic activity was basically zero-sum.[27] Both at the aggregate level and at the level of the firm, the ruling economic paradigm was one of a fixed pie, and the more one player got, the less there was for others. The idea that production and commerce actually could expand as the result of free exchange ripened slowly in the age of Enlightenment, coming to a crashing crescendo with the Scottish enlightenment of Hume and Smith and the French *économistes* of the physiocratic school. As argued persuasively by Ekelund and Tollison (1981, 1997), the mercantilist economy was to a great extent a rent-seeking economy, in which the incentive structure was largely designed for redistributive purposes. As Baumol (1993, 2002), Shleifer-Vishny (1998)

[27]This is precisely captured by Adam Smith (1976, p. 519): "nations have been taught that their interests consisted in beggaring all their neighbours. Each nation has been made to look with an invidious eye upon the prosperity of all the nations with which it trades, and to consider their gain as its own loss."

and others have argued at length, rent-seeking can be lethal to economic growth. This is not so much because of static deadweight losses (since these probably were not all that large) as much as because of the negative interaction that rent-seeking has with technological progress. First, much of mercantilist rent-seeking took the form of protective tariffs, which are widely agreed to be detrimental to technological progress and the international diffusion of best-practice techniques. To make things worse, many of the destructive wars in the eighteenth century were fought over real estate and colonial trade, at times destroying the sources of revenue. Secondly, rent-seeking activities tends to channel efforts and talents to non-productive activities such as lobbying and litigation and military careers. Finally, in a rent-seeking society, collective bodies will defend the technological status quo against the encroachment of new technology (since technological change often renders human skills and physical capital obsolete). It was the demolition of this structure which was the true mark of institutional progress.

It is possible to regard the Age of Enlightenment as in part a reaction against the economic *ancien régime*. This is less far-fetched than it may sound. Enlightenment-thought increasingly railed against the institutions that perpetuated rent-seeking. It should be noted that many of those institutions had not originally been designed as rent-seeking institutions, but eventually evolved into them. A paradigmatic example is the craft guild. Craft guilds in eighteenth century, as Adam Smith ([1776], 1976, pp. 139-144) argued forcefully, were costly to economic progress. They erected artificial barriers to entry in order to reap exclusionary rents, and on the whole were hostile to new technology.[28] The success of Britain, where guilds had been relatively weak since the mid seventeenth century, seemed to confim this belief. The literature on this matter has in recent years been subject to some serious revisionism, especially by S.R. Epstein (1998). Guilds were not *invariably* hostile to innovation, this literature argued, and in many ways they helped in the formation and intergenerational transmission of human capital. In a recent paper Sheilagh Ogilvie (2004) has cast doubt on this revisionist literature and shown that at least for Württemberg the negative view of craft guilds is supported by a great deal of historical evidence. It stands to reason that historically the evidence is mixed,

[28]The canonical statement is by the great Belgian historian Henri Pirenne: “the essential aim [of the craft guild] was to protect the artisan, not only from external competition, but also from the competition of his fellow-members.” The consequence was “the destruction of all initiative. No one was permitted to harm others by methods which enabled him to produce more quickly and more cheaply than they. Technical progress took on the appearance of disloyalty” (1936, pp. 185–86). For similar statements see e.g. Cipolla, 1968; Geyon and Guignet, 1980.

some guilds were more powerful than others, and it seems that over time their actual functions changed. By 1750, they had become in most places conservative and exclusionary, and it seems hard to imagine that radical innovation would have had much of a chance had they been still in control. Whenever guilds tried to maintain product-market monopolies, their incentives to innovate were lower than in a competitive market, and their incentives to protect their knowledge — through secrecy and limitations of the mobility of skilled labor —higher. This clearly had serious economic costs.

Abolishing or weakening craft guilds was a high priority for Enlightenment reformers, precisely because they impeded efficiency and economic growth. Attempts do carry out such programs were, in fact, attempted before 1789 by reform-minded politicians such as Turgot in France, Sonnenfels in Austria, and Campomanes in Spain. But these attempts ran into stiff resistance, in part from the vested interests that were threatened by such reforms, but also in part because the rents guilds collected were partially dissipated to the government and the fiscal consequences were often serious. Nothing but shock treatment could work, and on Feb. 16, 1791 the French guilds were abolished by fiat of the National Assembly. As the French armies advanced into the Low Countries, Italy, and Germany, this reform was invariably imposed. While suppression of the guilds did not lead to a completely free labor market and resistance to new technology in France could still be strong on occasion, by the time the dust settled on the Continent in 1815, this vestige of the economic *ancien régime* had largely vanished. By itself, the suppression of the guilds cannot be regarded a necessary condition for economic growth: long before 1791, manufacturers were able in many cases to move out of towns controlled by guilds, employ women and children, and find other ways around guild restrictions. But as a symptom of a general change in the attitude toward rent-seeking, the history of craft-guilds is illustrative.

A similar point can be made about the regulation of the grain trade. The original idea may have been for the government to try to help bring about a "moral economy," that is price stability through regulation and price control, but through much of the eighteenth century the system evolved into a way in which the rural sector subsidized would-be urban food rioters (Kaplan, 1976; Root, 1994; Persson, 2000).[29] Regulation took many forms beside price controls, including quality and weight-control of bread, government sponsored

[29] Among the "enlightened thinkers" who believed in free markets but would make an exception for this case of a necessity were the French economist Pierre de Boisguilbert and Jeremy Bentham.

granaries and export- and import regulation. In the second half of the eighteenth century, influenced by Enlightenment thought, the pressure for the liberalization of grain markets became increasingly strong. Physiocrat doctrine, much like Scottish political economy, was diametrically opposed to government regulation of the grain trade.[30] Under their influence regulation and price controls were gradually eliminated, although the movement was full of reversals: if the markets happened to have been liberalized in a year that was followed by scarcity, political pressures to bring it back could be too strong to withstand. The reforms introduced under Joseph II of Austria in the 1780s had to be reversed due to the dearth of 1788, and even Napoleon had to re-introduce maximum prices in 1812, though by 1815 liberal policies had triumphed.

Much as in the case of guilds, it can be argued that the liberalization of the grain trade was due to "real" factors. Specifically, Persson has maintained that improvements in transportation and long-distance trade made controls less necessary, as trade served as an alternative price stabilizer. In the longer run, this may well be correct, but it seems odd that liberalization would happen during the turbulent decades of the Revolutionary and Napoleonic wars, when trade disruptions and blockades were frequent. As in the case of the guilds, changes in ideology and a growing trust in the wisdom of free markets played an autonomous role beyond economic interests. Enlightenment economists were no less concerned with "poverty" as their mercantilist predecessors, but their idea of alleviating poverty was that free markets would raise overall prosperity, a rising tide that would raise all ships (Norberg, 2003).

Commercial policy was at center stage of the Enlightenment anti-mercantilist policy. Here, too, there was ambiguity. Not all Enlightenment writers were unambiguously pro free-trade.[31] Yet the theme of trade being a positive-sum game, so eloquently expounded by Adam Smith, had been advocated since the late seventeenth century and was becoming dominant in political economy by 1800. It is ironic, of course, that the wars of 1793-1815 caused by the French Revolution and its aftermath seriously disrupted international

[30]An early writer in the liberal tradition was the Siennese Sallustio Bandini writing in the 1730s. Tuscany turned out to be one of the first regions in Europe to dismantle its system of grain market management known as *abbondanza* (Persson, 2000, p. 142).

[31]David Hume, while certainly no mercantilist, was of two minds about it and noted that a "tax on German linens encourages home manufactures and thereby multiplies our people and our industry" (Hume, 1985, p. 98). Alexandre Vandermonde, a noted mathematician and scientist, who turned to economics late in life and taught it at the newly founded École Normale, and who knew his *Wealth of Nations* inside out, never converted to free trade and preferred the protectionist doctrines of Smith's contemporary, James Steuart (Gillispie, 2004, p. 513).

trade, causing the greatest mind of the economic enlightenment to include and entire chapter devoted to this phenomenon.[32] With the exception of a brief interlude following the 1786 Eden treaty, free trade was not to be seriously considered as a policy option until the 1820s. Smith himself (1976, p. 493) was not optimistic about free trade being established in Britain any more than "that Oceana or Utopia be even established in it." Yet the *pax Britannica* and the slow turn toward freer trade between 1820 and 1880 cannot be seen as the outcome of economic interests alone; persuasion on logical grounds was very much part of the story (Kindleberger, 1975). *The Wealth of Nations* may not have killed mercantilism by a single blow, it clearly placed it in a defensive corner.

What is not adequately emphasized, however, is that the main triumph of free trade was in the establishment of free *internal* trade. Internal tariffs were regarded by Enlightenment thinkers as the rent-seeking abomination that they were, and the elimination of the French internal tariff barriers followed the abolition of the abolition of the guilds. The U.S. commerce clause had been passed a few years earlier.[33] Internal trade in Sweden was liberalized in the late 1770s (Persson, 2000, p. 139). In Germany the matter was more complex, but the post-1815 movement toward a German *Zollverein* reflected the same sentiment. The system of tolls and duties on Germany's magnificent river system that hampered trade in the eighteenth century was dismantled. Arguably, the lion's share of gains from trade were secured through internal rather than external trade.

The sentiments against what we call "rent-seeking" are most eloquently reflected in the Enlightenment's aversion of monopolies, a widely shared view that must be explained by the historical fact that before the introduction of railroads it is very difficult to think of almost any eighteenth-century monopoly that had economic justification in terms of a high fixed cost component, lower transactions costs, or learning effects.[34] Barriers to entry were regarded as imposed by authorities, to create exclusionary rents. This

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[32]Ricardo ([1817], 1971), ch. XIX entitled "On sudden changes in the channels of trade"

[33]The Zollverein was preceded by the Prussian Maassen Tariff Law of 1818 which abolished all internal tariffs in Prussia and was influenced by a memorandum by G.J.C. Kunth, Beuth's mentor.

[34]Carlos and Nicholas's (1990; 1996) example of the trading companies as examples of "efficient monopolies" may be the one exception to this rule. Even in this case, the evidence has been contested (Ville and Jones, 1996).

repugnance was even extended to the patent system, where even Adam Smith could see some justification to it. The Society of Arts, established in 1754, explicitly ruled out making any awards to inventors who had patented their inventions.

Did these ideological changes have an effect? It is hard, in the end, to be sure that Enlightenment thought was more than St. Exupéry's king who commanded the sun to rise every morning. Mill's statement that a good cause seldom triumphs unless someone's interest is bound up with it does not imply that at times such good causes do not fail. Enlightenment-inspired reforms in the West came in four different waves. First, there were the post-1750 reforms introduced by so-called enlightened despots, which were often inspired by the writings of the *philosophes* but rarely had much staying power since they often ran up against deeply entrenched interests. Secondly, there were the "natural reforms" introduced in countries that had meta-institutions such as a Parliament with sufficient political adaptiveness to bring about induced institutional change, primarily Britain, which was able to pass such "rational" legislation as the Turnpike Act and the abolition of the Statute of Apprentices and Artificers and the Navigation Acts. In other countries revolution, whether indigenous or imported was necessary. Finally, there were "reactive" reforms in countries such as Prussia, as a result of reforms in nations viewed as competitors. The Enlightenment's influence on the French and American revolutions needs no elaboration. Equally well-documented is the enormous influence that *Wealth of Nations* had on policy makers, especially after Dugald Stewart, Smith's successor at Edinburgh, turned the book into a fountainhead of wisdom (Herman, 2001, pp. 229-30; see also Rothschild, 2001). Among Stewart's pupils were two future Prime Ministers, Palmerston and John Russell, as well as other senior officials, such as William Huskisson, the prime mover in British liberal reforms of the 1820's. His program was to remove all state support and protection for manufacturing and agriculture. Huskisson "zealously and consistently subscribed to the theories of Adam Smith. Smith's teaching, reflected in practically every reform in the twenties" (Brady, 1967, p. 133). In Germany, the influence of "the Divine Smith" on Prussian reformers has been thoroughly documented.

In economic history, scholars often write of technological *progress* but rarely of institutional *change*, and for good reason. But it could be argued that during the century between 1750 and 1850 there was something we might think of in those terms, because this is the age when rent-seeking in Europe was losing ground to productive commerce and production, an age in which markets became a little freer of regulation, and in which taxation and economic policy became less distributive. That it did not produce laissez faire economies, even in Victorian Britain, and that the movement was full of reversals and ambiguities requires no repetition. But "progress" there was all the same. The historical significance of this advance was that it eliminated the negative institutional feedback that before 1700 had wiped out economic growth. It is easy to see a counterfactual scenario in which the economic gains of the mule, the Watt engine, and the puddling and rolling process were swallowed up by tax-collectors, wars, protectionists, and distributive coalitions of various kinds. It is not hard to imagine the newly-entrenched technological status quo becoming increasingly more conservative and resisting further technological advances through political action. That this did *not* happen is the result of the double-action of the Enlightenment: while it increased useful knowledge and its effectiveness, at the same time it improved the incentives for its implementation and weakening the forces that would set it back. In that sense the enlightenment-inspired technological progress and institutional change created a powerful synergy, which in the end was responsible for the sustainability of what was started in Britain in the last third of the eighteenth-century and its diffusion to the societies that shared the enlightenment.

The roots of the European Enlightenment

Attributing the emergence of modern growth in the West to the Enlightenment in Europe leaves the question of the roots of the Enlightenment itself unanswered. To put it bluntly, we need to ask why Europe had an Enlightenment and other cultures such as Islam or China did not. Answering this question satisfactorily would be a huge undertaking. Linking it to previous events such as the emergence of humanism in Renaissance Europe or the Reformation only pushes the question further back. An alternative approach is to ask not why Europe had an Enlightenment altogether, but to postulate that "enlightened" ideas occurred in all societies, but that only in the "West" this movement was successful in the fashion described above. The victory of the Enlightenment was not just a case of growing and cumulative store of knowledge but the triumph of open and public knowledge over secret "arcane" knowledge, the victory of "mechanical" philosophy (e.g., verifiable knowledge about natural regularities) over "occult philosophy" dealing with mystical and unobservable entities, and the victory . How, then, did the good guys win?

Europe's uniqueness was obviously *not* that it was monetized, commercialized, and enjoyed "good" governance. "Capitalism" — whatever maybe exactly meant by that term in the context of early eighteenth century Europe — seems too vague a concept to be of much help. What seems unique to Europe in the period leading up to and including the Enlightenment is the growing opportunity for critics, sceptics, and innovators to try their ideas out in a marketplace for ideas and to survive the experience. The notion that Europe was deeply hostile to "heretics" based on the tragic experience of such figures as Giordano Bruno and Miguel Servetus is fundamentally mistaken. The picture of Europe in the period 1500-1750 is one in which innovative, often radical, intellectuals are able to play one political authority against one another: different polities against each other, and when necessary also central vs. local power and spiritual against secular authority. By moving from one place to another when the environment became too hostile, the members of the intellectual class ("clerisy" as they are sometimes called) could remain active in the transnational community of scholars, the "Republic of letters." Iconoclastic scholars who had brought upon themselves the ire of the local establishment usually went elsewhere. Martin Luther is only the most famous rebel who successfully played this game.[35]

The fragmentation of power and the competitive "states system" (the term is slightly anachronistic for the principalities and bishoprics that enjoyed some measure of political autonomy in the seventeenth and eighteenth centuries) has been argued to assist Europe in another way. Paul David (2004) has argued that many rulers competed to attract to their courts the reputable scientists, in part because some skills could come in handy, but largely as a signaling device (that, is to show off). The competition for the "best" scientists between European rulers required open science as a solution to the asymmetric information problem that rulers faced, namely to identify the truly leading scientists of their generation. Only within communities ("invisible colleges") in which full disclosure was exercised, he argues, could credible reputations be

[35]Among the others, the case of the famously pugnacious physician and chemist Paracelsus who publicly burned the books of the canonical authorities in Basel in 1527 is illustrative. The Moravian religious leader and educational reformer Jan Amos Comenius, fleeing his native Czech lands from the Imperial forces, repeatedly found himself in politically uncomfortable circumstances and spent time in Poland, London, Paris, Sweden, and Amsterdam. In 1682, Pierre Bayle, a philosopher and polymath who annoyed Catholics and Calvinists in equal measure, left France and settled in Rotterdam. Similar mobility was practiced by most of the eighteenth-century *philosophes*, although by that time many intellectual establishments had realized the futility of repressing intellectual innovation and basically gave up on outright suppression of new ideas.

established that would allow wealthy patrons distinguish truly distinguished scientists from fraudulent ones. Open science then emerged as a best strategy for scientists competing for patronage.[36] The competition of different institutions for the superstars of science meant that, at least for the very best, they could set their own research agendas and appropriate the benefits of research, such as they were, and that few governments had the power to suppress views they considered heretical or subversive.

We may also point to specific institutional changes that encouraged both the growth of intellectual innovation and its growing bias toward "usefulness" — though the latter term needs to be treated with caution. Perhaps the central development was a change in the relation between the world of production — farmers, merchants, manufacturers, as well as government agencies engaged in military and infrastructural projects — and the world of intellectuals. The idea that *ars sine scientia nihil est* (practice is worthless without theory), first enunciated in Renaissance Italy, slowly won ground. Natural philosophers were increasingly retained and engaged in practical matters where, it was believed, they could bring to bear their knowledge of nature to solve problems and increase efficiency. Examples are easy to find. The career of Johann Joachim Becher, whose chemical theories constituted the foundation of eighteenth century phlogiston chemistry, but who also worked for a variety of European government as an engineering consultant and argued that his knowledge of medicine qualified him to write about politics because in both cases he was maximizing a social welfare function (Smith, 1997, p. 69). Less pretentious was the Scottish mathematician Colin MacLaurin who solved the rather hard problem of measuring the quantity of molasses in irregularly shaped barrels by the use of classical geometry (Grabiner, 1998). Scottish chemists such as William Cullen and Joseph Black were much in demand as consultants to improving farmers and ambitious textile manufacturers (Mokyr, 2002, pp. 50-51). From the measurement of longitude (perhaps the most well-defined single problem that the age of Enlightenment solved) to the improvement of waterpower by applying mathematics to the growing science of hydraulics, the knowledge of various "applied philosophers" was brought to bear on matters of

[36]David's argument seems to assume that the main motive of natural philosophers was to secure such patronage positions rather than to impress their peers or contribute to knowledge. It also tends to overstate the ability of the scientific community to reach consensus on who were true winners in this tournament and the costs to princes associated with the sinecure awarded to mediocrities.

technology.[37] The same is true for knowledge of plants and animals.[38]

The growing conviction that this knowledge had (at least in expectation) a positive social marginal product meant of course that the demand for useful knowledge increased. This created the standard problem of intellectual property rights to useful knowledge. The interesting way in which was solved was by taking advantage of the fact that the creators of useful knowledge sought credit rather than profit from their work. Such credit, in some cases, was necessary to assure them some reservation price, mostly in terms of a sinecure: a pension, an appointment at a court or a university, or a sponsored job by an academy or scientific society.[39] The rules of the game in the Republic of Letters, as they were established in the second half of the seventeenth century were credit by priority subject to verification. This "credit" was a property right in that it attributed an innovation unequivocally to the person responsible.[40] This prestige was then often correlated with some appointment that provided them with their reservation price, though the correlation was far from perfect. Others, such as Henry Cavendish. Joseph Banks, and Antoine Lavoisier were financially independent and did not need or expect to be compensated for their scientific work.

The other factor that facilitated the success of the Enlightenment as an intellectual movement in Europe was the institutional fluidity of intellectual activity. No single set of institutions dominated thought in Enlightenment Europe the way the Church had dominated in the medieval period and the way the Confucian mandarinate dominated Chinese thought. In Europe such institutional domination was absent, and within the Republic of Letters there was free entry and furious competition for patronage and clients. Peter Burke

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[37]Leonhard Euler, the most talented mathematician of the age, was concerned with ship design, lenses, the buckling of beams, and (with his less famous son Johann) contributed a great deal to hydraulics.

[38]Naturalists of various types were equally regarded as contributing to the wealth of their nations. Originally Botany and Chemistry were subjects ancillary to medicine, and their main proponents, such as Stahl, Cullen, and Boerhaave, were famous primarily as physicians. In the second half of the century this changed. Linnaeus's belief that skillful naturalists could transform farming was widely shared and inspired the establishment of agricultural societies and farm improvement organizations throughout Europe. after 1750, botanists, horticulturalists, and agronomers were working hand-in-hand through publications, meetings, and model gardens to introduce new crops, adjust rotations, improve tools and better management.

[39]The economics of open science resemble in many ways the economics of open source software development (Lerner and Tirole, 2004) which has found that signalling to outsiders, peer recognition, and direct benefits all play a role.

[40]In an earlier time, the absence of clear-cut rules discouraged open knowledge. Thus the architect Francesco di Giorgio Martini (1439-1501) complained that "the worst is that ignoramuses adorn themselves with the labors of others and usurp the glory of an invention that is not theirs. For this reason the efforts of one who has true knowledge is oft retarded." Cited by Eamon, 1994, p. 88.

(2000, pp. 37, 48) has suggested that universities tended to suffer from "institutional inertia" and become conservative over time, so that only the founding of new ones kept them creative and lively. Professor Martin Luther was teaching theology at an institution that was only fifteen years old, and the University of Leyden, founded in 1575 as a Calvinist University, became a major innovator in its curriculum. But universities had to contend with the academies and courts of Europe to attract the best minds of Europe. The decentralized and multifocal distribution of wealth and power in Europe between Luther and Lavoisier led to a world of intellectual competition in which knowledge was both transmitted and augmented in ever more effective fashion.

There were other reasons for the success of the European Enlightenment. The *philosophes* of the eighteenth century were not a marginal group, struggling for recognition. Despite their opposition to the existing arrangements and their dreams of reform and improvement, they were more often than not part of the establishment, or, better-put, part of *some* establishment. The triumph of the *philosophes* must be explained by their ability to act against the status quo from within the establishment. Many of the leading lights of the eighteenth century *philosophes* and political economists were well-born and politically well-connected. Even when they ran afoul of the regime, the relations rarely degenerated into hostility. This "cosy fraternizing with the enemy," as Gay (1966, p. 24), calls it did not come without a price, but it allowed the *philosophes* to be politically effective without necessarily threatening the status quo. In France, this relationship in the end imploded (though it was soon restored), but elsewhere it made it possible for their ideas to be adopted by the men who voted on policy decisions. All the same, throughout Europe the Enlightenment was a decentralized and free-enterprise endeavor, sometimes-tolerated but rarely managed or sponsored by governments. Yet it was not unorganized: enlightenment ideas found expression in the myriad of friendly societies, academies, masonic lodges and similar organizations of people who shared beliefs and traded knowledge. To be sure, there were a few figures of political power who were associated with and influenced by the Enlightenment, the best known of whom were the so-called enlightened despots and some of their ministers. It stands to reason that an intellectual movement such as this can fail either because it is too close to the government or because it so marginalized that it can be ignored. Much of the European Enlightenment fell in between.

A brief comparison with China is perhaps instructive here. A dismissive argument that China never had an Enlightenment is incomplete. Some of the developments that we associate with Europe's Enlightenment resemble events in China remarkably, but the differences between the European and the Chinese Enlightenments are as revealing as the similarities. The Chinese attempt at Enlightenment in the eighteenth century 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). It was based on rigorous research, demanded proof and evidence for statements, and shunned away from leaps of faith and speculation. It sounds promising, but in the end these 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).[41] Equally significantly, unlike the European Enlightenment, the Chinese movement remained by and for the mandarinate, the ruling Confucian elite, which had little inclination for material progress.[42]

There were attempts at serious intellectual reform in China in the period under discussion. It could well be argued that the seeds of a Chinese Enlightenment were sown by Fang Yi-Chih (1611-1671), the author of a book meaningfully entitled *Small Encyclopedia of the Principles of Things*, which discussed potentially useful forms of propositional knowledge such as meteorology and geography. He was familiar with Western writings and quite influential in the Kaozheng school of the eighteenth century. While Peterson (1975, p. 401) has suggested that Fang's work paralleled the secularization of science in Europe, Sivin (1975) has compared him with European scholasticism and feels that his work was "antiquated."

The literature about the Chinese Enlightenment, conveniently summarized in Elman, may have overstated its bias to literary and philological topics. There was considerable interest in astronomy and mathematics, and Chinese scholars carefully examined useful knowledge that seeped in from the West. Scholars

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[41]For instance, the great scholar Tai Chen who was "a truly scientific spirit ... whose principles hardly differed from those which in the West made possible the progress of the exact sciences. But this scientific spirit was applied almost exclusively to the investigation of the past" (Gernet, 1982, p. 513).

[42]The literature about Confucian beliefs and practicality remains controversial. The Japanese sinologist Hattori Unichi flatly stated that Confucianism is neither utilitarian nor positivistic. He maintained that classical Confucianism and neo-Confucianism in general justify righteous action in terms of virtuous motivations rather than in term of utility. These remarks point to an apparent ambivalence concerning practicality in Confucian philosophy; Confucian philosophy is practical in the sense of being concerned with morality, social interaction, and political activity, but it is not practical in the sense of being concerned with economy and technology.

such as Mei Wending (1633-1721) carefully compared Western mathematics and astronomy to Chinese knowledge, and pointed to advances that the West had made, though Chinese scholars often took the trouble to try to show that this knowledge had already existed in ancient China. What was missing in China, however, were the institutional bridges that eighteenth century Europe built between the *savants* and the *fabricants*. By 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, the navigator, the European enlightenment redefined the agenda of research. Moreover, it placed best-practice knowledge and investigative techniques at the disposal of innovators, thus streamlining technological progress.

The tradition of Kaozheng scholarship contained many elements that we associate with the European scientific revolution and the subsequent Enlightenment (Elman, 2001). Kaozheng scholars had 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. The scholarly community had a keen sense of assigning priority, and a notion of progress was implicit in their scholarship. Much like European scholars, Chinese Enlightenment 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 in diagrams and maps. Gu Donggao's (1679-1759) book used them for information on the pre-Qin and Han periods (722-481BC) and Yan Roju (1636-1704) counted and analyzed citations from classical poetry. The scientists of the early Ch'ing period were convinced that their mathematical tools (trigonometry and geometry) had the power to explain nature as well as 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."

A telling example is the publication of Chinese encyclopedias. It is surely wrong to believe that Europeans were the only ones to realize the importance of reference books. The vast efforts of the Chinese Ch'ing emperors in publishing encyclopedias and compilations of knowledge under the Emperors K'ang Chi and Qian Long, 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 cost. It stands to reason that 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). 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 with the European encyclopedias, which were sold in large numbers.[43] It is revealing, for instance, 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.[44] China may not have exactly European-style universities, but it had numerous "academies" (*shuyuan*) — in which candidates for the state bureaucracy could cram before the examinations (Elvin, 2004, p. 58).

Or consider the example of a seventeenth century Chinese scholar Chu Shun-shui, one of the few Chinese intellectuals who can be compared with a European intellectual in his itinerancy. His knowledge was quite broad and extended to fields of practical knowledge such as architecture and crafts. Fleeing from China (he remained a supporter of the Ming dynasty, overthrown in 1644) first to Annam (Vietnam) and then to Japan, he had quite a following there. Chu Shun-shui, in Julia Ching's words, was hardly a purely abstract philosopher, but "the investigation of things referred to less to the metaphysical understanding of principle of material forces, and more to coping with concrete situations. At the same time, the extension of knowledge applied not only to knowledge of the Confucian classics, but also to all that is useful in life". This, again, sounds promising, but Chu's work remained unknown in China.

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." The "chasm" between its

[43]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, the total number of encyclopedias alone, not counting the many compendia, dictionaries, lexicons, and similar books published in the eighteenth century, the total number of reference books is a large multiple.

[44]Much different from the works of European encylopedists, the *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).

scientists and those who made things remained all but watertight.[45] Mathematics and astronomy were applied for instance to reconstruct the size and shape of historical ceremonial bronze bells or reconstruct ancient carriages. Despite the fact that the *Kaozheng* movement was born 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 the Imperial government in China was not interested in steering research in a direction that could benefit the economy, there seems to have been no other agency that had the interest or the capacity. The agenda of Chinese scholarship remained retrospective: to prove ancient sages right and to perform exegesis on their writings is a respectable intellectual activity, but it does not bring about the developments that Lucas could not stop thinking about. It seems wrong to dub the Chinese experience a failure. What is exceptional, indeed unique, is what happened in eighteenth century Europe.

The European enlightenment pushed a dual platform that was radical and revolutionary: reform institutions to promote efficiency and innovation, and bring the full force of human knowledge to bear on technology.[46] Without that synergy, long-term economic growth in the West might not have happened either. The Enlightenment was an indispensable element in the emergence of modern economic growth. Its belief in social progress through reason and knowledge was shocked repeatedly as the superiority of reason was thrown in doubt.[47] But the idea of useful knowledge as an engine of social progress has not lost any of its power, even as it was challenged, toned down, and refined in the two centuries since 1800. There was nothing pre-ordained or inevitable about that course of history. Indeed, it seems ex ante extremely unlikely, and any competent economic historian can point to a dozen junctures where the process could have been derailed. The fruits of these changes were, of course, very late in coming. Economic growth, in the sense that Lucas had in mind, does not take off *anywhere* before 1830. And yet from a long-run perspective, the striking thing is

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[45]This is well summed up 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."

[46]Cohen (2004, p. 131) raises a similar point: how could one explain the simultaneous confluence of two seemingly independent streams of historical events, namely the growth of science and the willingness of Europeans to invest in large scale projects embodying the new useful knowledge.

[47]Indeed, even during the Enlightenment, the supremacy of reason over sentiment and sensitivity has been shown to be a flawed concept (Riskin, 200

not that it happened so long after the necessary precedent intellectual changes, but that it happened at all.

References

Alder, Kenneth. 1997. *Engineering the Revolution: Arms, Enlightenment, and the Making of Modern France.* Princeton, N.J.: Princeton University Press.

———. 1998. "Making Things the Same: Representation, Tolerance and the End of the Ancien Régime in France." *Social Studies of Science* 28, no. 4 (Aug.), pp. 499–545.

Allan, D.G.C.1979. *William Shipley: Founder of the Royal Society of Arts.* London: Scolar Press.

Bauer, Wolfgang. 1966. "The Encyclopedia in China," *Cahiers d'Histoire Mondiale* 9, pp. 665-91.

Baumol, William J. 1993. *Entrepreneurship. Management, and the Structure of Payoffs*. Cambridge, Mass.: MIT Press.

Baumol, William. 2002. *The Free-Market Innovation Machine: Analyzing the Growth Miracle of Capitalism*. Princeton, NJ: Princeton University Press.

Blaut, James M. 2000. *Eight Eurocentric Historians*. New York: Guildford Press.

Bourde, André J. 1967. *Agronomie et Agronomes en France au XVIIIe Siècle.* Vol. 1. Paris: S.E.V.P.E.N.

Bowers, Brian. 1991. *Michael Faraday and the Modern World*. Wendens Ambo (Essex): EPA Press.

Brady, Alexander. 1967. *William Huskisson and liberal reform: an essay on the changes in economic policy in the twenties of the nineteenth century*. London: Oxford University Press.

Burke, Peter. *A Social History of Knowledge.* Cambridge: Polity Press, 2000.

Cardwell, Donald S. L. 1994. *The Fontana History of Technology*. London: Fontana Press.

Carlos, Ann and Nicholas, Stephen. 1990. "Agency Problems in Early Chartered Companies: The Case of the Hudson's Bay Company." *Journal of Economic History* 50(4): 853-75.

———. 1996. "Theory and History: Seventeenth-Century Joint-Stock Chartered Trading Companies." *Journal of Economic History* 56(4): 916-24.

Cipolla, Carlo. 1968. "The Economic Decline of Italy." In Brian Pullan, ed., *Crisis and Change in the Venetian Economy in the Sixteenth and Seventeenth Centuries*. London: Methuen.

Cohen, H. Floris. 2004. "Inside Newcomen's Fire Engine: the Scientific Revolution and the Rise of the Modern World." *History of Technology* 25, pp. 111-132.

Darnton, Robert. 1979. *T he Business of Enlightenment,* Cambridge: Harvard University Press.

Daumas, Maurice, and André Garanger. 1969. "Industrial Mechanization." In Maurice Daumas, ed., *A History of Technology and Invention*, vol. II. New York: Crown.

David, Paul A. 2004. "Patronage, Reputation, and Common Agency Contracting in the Scientific Revolution." unpub. ms., Stanford University, Aug.

Deyon, Pierre, and Philippe Guignet. 1980. "The Royal Manufactures and Economic and Technological Progress in France before the Industrial Revolution." *Journal of European Economic History* 9, no. 3 (Winter), pp. 611–32.

Dickinson, H.W., and Jenkins, Rhys. *James Watt and the Steam Engine.* London: Encore editions, 1927.

Eamon, William. 1994.

Ekelund, Robert B. Jr., and Tollison, Robert D., 1981. *Mercantilism as a Rent-Seeking Society*. College Station: Texas A&M University Press.

———. 1997. *Politicized Economies: Monarchy, Monopoly, and Mercantilism.* College Station: Texas A&M University Press.

Elman, Benjamin. 2001. *From Philosophy to Philology: Intellectual and Social Aspects of Change in Late Imperial China*, 2nd ed., Los Angeles: UCLA Asia-Pacific Institute.

Elvin, Mark. 2004. "Some Reflections on the Use of 'Styles of Scientific Thinking' to Disaggregate and Sharpen Comparisons between China and Europe," *History of Technology*, Vol. 25, pp. 53-103.

Epstein, S. R. 1998. "Craft Guilds, Apprenticeships, and Technological Change in Pre-industrial Europe." *Journal of Economic History* 58, no. 3 (Sept.) pp. 684–713.

Epstein, S.R. 2004. "Knowledge-Sharing and Technological Transfer in Premodern Europe, C. 1200 - C. 1800." Unpublished manuscript, presented to the EHA Annual Conference, San Jose.

Ferguson, Eugene S. 1971. "The Measurement of the 'Man-Day'," *Scientific American* 225, pp. 96–103.

Gascoigne, John . *Joseph Banks and the English Enlightenment*. Cambridge: Cambridge University Press, 1994.

Gay, Peter. 1966. *The Enlightenment: an Interpretation. The Rise of Modern Paganism*. New York: W.W. Norton.

Gernet, Jacques. 1982. *A History of Chinese Civilization*. Cambridge: Cambridge University Press.

Gillispie, Charles C. *Science and Polity in France at the end of the Old Regime.* Princeton: Princeton University Press, 1980.

Gillispie, Charles C. 2004. *Science and Polity in France: The Revolutionary and Napoleonic Years*. Princeton: Princeton University Press.

Goldstone, Jack A. 2002. "Efflorescences and Economic growth in World History: Rethinking the 'Rise of the West' and the Industrial Revolution." *Journal of World History* Vol. 13, No. 2, pp. 323-89.

Golinski, Jan. 1992. *Science as Public Culture: Chemistry and Enlightenment in Britain, 1760–1820*. Cambridge: Cambridge University Press.

Grabiner, Judith V. 1998. "'Some disputes of Consequence': MacLaurin among the Molasses Barrels," *Social Studies of Science* 28, No 1., pp. 139-168.

Gray, John. 1995. *Enlightenment's Wake: Politics and Culture at the Close of the Modern Age*. London; New York: Routledge.

Greif, Avner. "Cultural beliefs and the organization of society: a historical and theoretical reflection on collectivist and individualist societies." *Journal of Political Economy* 102, no. 5 (1994): 912-941.

________. *Institutions: Theory and History.* Cambridge: Cambridge University Press. Forthcoming, 2005.

Harley, C. Knick. 1998. "Re-assessing the Industrial Revolution: a Macro View." In Joel Mokyr, ed., *The British Industrial Revolution: An Economic Perspective*. Boulder: Westview Press, pp. 160-205.

Harris, John R. 2001. *Industrial Espionage and Technology Transfer*. Aldershot, Eng.: Ashgate.

Herman, Arthur. 2001. *How the Scots Invented the Modern World*. New York: Crown.

Hills, Richard L.1989. *Power from Steam: a History of the Stationary Steam Engine*. Cambridge: Cambridge University Press.

Horkheimer, Max and Adorno, Theodore W. 1976. *Dialectic of the Enlightenment*. New York: Continuum.

Hunter, Michael. 1989. *Establishing the New Science : the Experience of the Early Royal Society.* Woodbridge, Suffolk, and Wolfeboro, N.H.: Boydell Press.

Inkster, Ian. 2004. "Potentially Global: A Story of Useful and Reliable Knowledge and Material Progress in Europe, ca. 1474-1912." Unpub. ms.

Jacob, Margaret C. 2004."Putting Science to Work." Unpublished paper, presented to the History of Science meetings in Halifax, NS, July.

Jacob, Margaret C. and Larry Stewart. 2004. *Practical Matter: Newton's Science in the Service of Industry and Empire, 1687-1851*. Cambridge, MA: Harvard University Press.

Jones, Eric L. 1981. *The European Miracle: Environments, Economies and Geopolitics in the History of Europe and Asia*. 2d ed. 1987. Cambridge: Cambridge University Press.

———. 1988. *Growth Recurring.* Oxford: Oxford University Press.

Kaplan, Steven L. 1976. *Bread, Politics and Political Economy in the Reign of Louis XV*. The Hague: Martinus Nijhoff.

Kranakis, Eda.1992. "Hybrid Careers and the Interaction of Science and Technology." In *Technological Development and Science in the Industrial Age*, edited by Peter Kroes and Martijn Bakker, 177–204. Dordrecht: Kluwer,

Keynes, John Maynard. 1936. *The General Theory of, Employment, Interest, and Money*. New York: Harcourt, Brace.

Keyser, Barbara Whitney. 1990. "Between Science and Craft: the Case of Berthollet and Dyeing." *Annals of Science* 47, no. 3 (May), pp. 213–60.

Kindleberger, Charles P. 1975. "The Rise of Free Trade in Western Europe, 1820-1875" *The Journal of Economic History*, Vol. 35, No. 1, (March), pp. 20-55.

Landes, David S. 1998. *The Wealth and Poverty of Nations: Why Some Are So Rich and Some So Poor*. New York: W. W. Norton.

Lerner, Josh and Tirole, Jean. 2004. "The Economics of Technology Sharing: Open Source and Beyond." NBER Working paper 10956 (Dec.).

Levere, T.H., and Turner, G. L' E. 2002. *Discussing Chemistry and Steam: The Minutes of a Coffee House Philosophical Society 1780-1787*. Oxford: Oxford University Press.

Lindqvist, Svante. 1990. "Labs in the Woods: The Quantification of Technology during the Late Enlightenment." In Tore Frängsmyr, J. L. Heilbron, and Robin E. Rider, eds., *The Quantifying Spirit in the 18th Century,* pp. 291–314. Berkeley: University of California Press.

Lipsey, Richard G., Kenneth Carlaw and Cliff Bekar, *Economic Transformations: General Purpose Technologies and Sustained Economic Growth*, New York: Oxford University Press (forthcoming).

Lucas, Robert E. 1988. "On the Mechanics of Economic Development," *Journal of Monetary Economics,* Vol. 22, pp. 3-42.

Mokyr, Joel. 2002. *The Gifts of Athena: Historical Origins of the Knowledge Economy*. Princeton: Princeton University

Press.

________.2004. "Accounting for the Industrial Revolution," in Paul Johnson and Roderick Floud, eds., *The Cambridge Economic History of Britain, 1700-2000.* Cambridge University Press, Vol. I, pp. 1-27.

________. 2005a"Long-term Economic growth and the History of Technology." In *The Handbook of Economic growth*, edited by Philippe Aghion and Steven Durlauf. Forthcoming, 2005.

________. 2005b"Mercantilism, the Enlightenment, and the Industrial Revolution," Presented to the Conference in Honor of Eli F. Heckscher, Stockholm, May 2003. Forthcoming in Ronald Findlay, Rolf Henriksson, Hokan Lindgren, and Mats Lundahl (eds), *Eli F. Heckscher (1879-1952): A Celebratory Symposium.* Cambridge, MA: MIT Press.

———— . 2005c. "The Intellectual Origins of Modern Economic Growth" *Journal of Economic History,* forthcoming.

Needham, Joseph. 1969. *The Grand Titration*. Toronto: University of Toronto Press.

Norberg, Kathryn. 2003. "Poverty." in Alan Charles Kors, ed. *Encyclopedia of the Enlightenment.* Vol 3, pp. 347-53. New York: Oxford University Press.

North, Douglass C. 1981. *Structure and Change in Economic History*. New York: W. W. Norton.

North, Douglass C. and Barry Weingast. 1989. "Constitutions and Commitment: The Evolution of Institutions Governing Public Choice in Seventeenth Century England." *Journal of Economic History* 49, no. 4 (Dec.), pp. 803–32.

Ogilvie, Sheilagh. 2004. "Guilds, Efficiency, and Social Capital: Evidence from German proto-industry." *Economic History Review* 57, no. 2, pp. 286-333.

Pannabecker, John R.1996. "Diderot, Rousseau, and the Mechanical Arts: Disciplines, Systems, and Social Context." *Journal of Industrial Teacher Education* 33, no. 4, pp. 6-22.

________. 1998. "Representing Mechanical Arts in Diderot's Encyclopédie." *Technology and Culture* 39, no. 1 (Jan.), pp. 33–73.

Persson, Gunnar. 2000. *Grain Markets in Europe, 1500-1900: Integration and Deregulation*. Cambrdidge: Cambridge University Press.

Pirenne, Henri. 1936. *Economic and Social History of Medieval Europe*. New York: Harcourt Brace & World.

Priestley, Joseph. 1768. *An Essay on the First Principles of Government and on the Nature of Political, Civil and Religious Liberty.* London: Printed for J. Doosley in Pall Mall.

Pomeranz, Kenneth. 2000. *The Great Divergence: China, Europe, and the Making of the Modern World Economy*. Princeton, N.J.: Princeton University Press.

Porter, Roy. 2000. *The Creation of the Modern World: The Untold Story of the British Enlightenment*. New York: W.W. Norton.

Reynolds, Terry S. 1983. *Stronger than a Hundred Men: A History of the Vertical Water Wheel*. Baltimore: Johns Hopkins Press,

Ricardo, David ([1817], 1971). *Principles of Political Economy*, ed. R.M. Hartwell. Harmondsworth: Pelican Books.

Root, Hilton. 1994. *The Fountain of Privilege: Political Foundations of Markets in Old Regime France and England.* Berkeley and Los Angeles: University of California Press.

Rostow, Walt W. 1975. *How it all began: Origins of the Modern Economy.* New York: McGraw Hill.

Rothschild, Emma. 2001. *Economic Sentiments: Adam Smith, Condorcet, and the Enlightenment.* Cambridge: Harvard University Press.

Schofield, Robert. 1963. *The Lunar Society of Birmingham*. Oxford: Clarendon Press.

Shleifer, Andrei and Vishny, Robert. 1998. *The Grabbing Hand : Government Pathologies and their Cures*. Cambridge, MA: Harvard University Press.

Sivin, Nathan. 1975. "Wang Hsi-shan," in *Dictionary of Scientific Biography*, edited by Charles Coulston Gillispie. New York: Charles Scribner's Sons, Vol. XIV, pp. 159-68.

———. 1995. "Why the Scientific Revolution did not take Place in China—or didn't it?" in *Science in Ancient China*. Aldershot: Variorum.

Smil, Vaclav. 2005. *Creating the Twentieth century: Technical Innovations of 1867-1914 and their Lasting Impact.* New York: Oxford University Press, 2005.

Smith, Adam. 1978. *Lectures on Jurisprudence.* Edited by R.L. Meek et al. Oxford: Oxford University Press.

________. 1976. *An Inquiry into the Nature and Causes of the Wealth of Nations*. Cannan ed. Chicago: University of Chicago Press. Reprint. Oxford: Oxford University Press.

Smith, Pamela. *The Business of Alchemy*.

Spence, Jonathan. 1990. *The Search for Modern China*. New York: W.W. Norton.

Sprat, Thomas. 1702. *The History of the Royal-Society of London, for the Improving of Natural Knowledge.* London:

Printed for Rob. Scot, Ri. Chiswell, Tho. Chapman, and Geo. Sawbridge.
Stewart, Larry. 1992. *The Rise of Public Science*. Cambridge: Cambridge University Press.
———. 2004."The Laboratory and the Manufacture of the Enlightenment." Unpublished Manuscript, University of Saskatchewan.
Thompson, William Count Rumford. 1876. *The Compete Works of Count Rumford.* London: *The Compete Works of Count Rumford* London: the American Academy of Arts and Sciences, MacMillan & Co.
Uglow, Jenny. *The Lunar Men: Five Friends whose Curiosity changed the World.* New York: Farrar, Strauss and Giroux 2002.
Ville, Simon and Jones, S.R.H. 1996."Efficient Transactors or Rent-Seeking Monopolists? The Rationale for Early Chartered Trading Companies." *Journal of Economic History*. 56(4): 898-915.
Wong, R. Bin. 1997. *China Transformed: Historical Change and the Limits of European Experience.* Ithaca: Cornell University Press.
Young, Arthur. *Political Essays concerning the Present State of the British Empire*. London: printed for W. Strahan and T. Cadell, 1772.
Zilsel, Edgar. 1942. "The Sociological Roots of Science." In *American Journal of Sociology* 47, no. 4 pp. 544-60.