The Knowledge Society:
Theoretical and Historical Underpinnings

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1. Useful Social Knowledge: some definitions

What is useful social knowledge? The term includes two elements, "social" and "useful" and I will deal with them in succession. What does it mean for an entire society to know something? The only sensible way of defining knowledge at a social level is as the *union of all the sets of individual knowledge of the members of this society*. It requires some simplifying assumptions – for instance, that we agree about who belongs and who does not belong to society. It also means that individual "knowledge" can be defined abstracting from the degree of certainty that the individual has in the correctness of this knowledge (which I will discuss in more detail below). An immediate corollary of the definition is that the set of knowledge contains contradictory elements: it usually contains elements inconsistent with one another (some people still believe the earth is flat or that AIDS is not caused by the HIV virus). Another obvious characteristic is that the "truth" of knowledge is irrelevant (by "truth" was can only mean that it conforms to the consensus views of our own time). In other words, "knowledge" pertains to what an individual *believes* to be true

This definition is consistent with our intuitive notion of the concept of an invention or a discovery – at first only one person has it, but once that happens society as a whole feels it has acquired it. When Einstein discovered relativity in 1905 it was felt that all of humanity had, even though only the minutest fraction could understand it (or even knew what it was all about). Knowledge differs from information in that it exists only in the human mind. It can be stored in external storage devices such as books, drawings, and artifacts but such knowledge is meaningless unless it can be transferred to and acquired by an actual person. Such a definition immediately requires a further elaboration: if one person possesses certain knowledge, how costly is it for others to acquire it? I shall refer to these costs as *access costs* and they are central to any understanding of the process of knowledge accumulation.

This concept of access costs is at the heart of the idea of a "technological society." Knowledge is shared and distributed, and its transmission through learning is essential for such a society to make effective use of it. Between the two extremes of a society in which all knowledge acquired by one member is "episodic" and not communicated to any other member, and the other extreme in which all knowledge is shared through some monstrous super network as envisaged by Robert Wright (2000), there was a reality of partial and costly sharing and access. But these access costs were not historically invariant, and their development is one of the keys to technological change. Basically, these costs depended on two types of factors, technological and cultural. The technological factors determined the physical costs of disseminating information including communications, transportation, printing, and the technology of organizing information. The cultural factors determined to what extent the people who possessed the knowledge were willing to share it and place it in social domain.

What kind of knowledge do I have in mind? What makes knowledge "useful? The term "useful knowledge" was used by Simon Kuznets (1965, pp. 85–87) as the source of modern economic growth. One could debate at great length what "useful" means. In what follows, I am motivated by the centrality of technology. Because technology in its widest sense is the manipulation of nature for human material gain, I confine myself to knowledge of natural phenomena and regularities that exclude the human mind and social institutions. To be sure, a great deal of important knowledge, including economic knowledge, involves people and social phenomena: knowledge about prices, laws, relationships, personalities, the arts, literature, and so on. I should add right away that some "technologies" are based on the regularities of human behavior (e.g., management science and marketing using psychology) and therefore might be considered part of this definition. Moreover, some segments of useful knowledge thus defined are rather unlikely to be applied to any technical purpose (e.g., astronomical knowledge about remote galaxies). Despite some gray areas and ambiguities, I shall maintain this definition.

2. **Propositional and Prescriptive Knowledge**

The set of useful knowledge defined above can be partitioned into two subsets: one is the knowledge that catalogs natural phenomena and regularities ("knowledge of what"), which I will call *propositional knowledge.* The other is the knowledge that prescribes certain actions that constitute the manipulation of natural phenomena for human material needs ("production") and which I will call *prescriptive knowledge.*

A few notes on the characteristics of those two sets. Propositional knowledge contains what we call "science" (formal and consensual propositional knowledge) as a subset, but it contains a great deal more than science. Through most of human history, indeed, science was a negligible subset, and it is one of the hallmarks of technological modernity that the relative size of the scientific component of propositional knowledge has grown in relative importance. Propositional knowledge also contains practical informal knowledge about nature such as the properties of materials, heat, motion, plants, and animals; an intuitive grasp of basic mechanics (including the six "basic machines" of classical antiquity: the lever, pulley, screw, balance, wedge, and wheel); regularities of ocean currents and the weather; and folk wisdoms in the "an-apple-a-day-keeps-the-doctor-away" tradition. Geography is very much part of it: knowing where things are is logically prior to the set of instructions of how to go from here to there. It also includes what Edwin Layton (1974) has termed "technological science" or "engineering science" and Walter Vincenti (1990) has termed "engineering knowledge," which is more formal than folk wisdom and the mundane knowledge of the artisan, but less than science. Engineering knowledge concerns not so much the general "laws of nature" as the formulation of quantitative empirical relations between measurable properties and variables, and imagining abstract structures that make sense only in an engineering or a chemical context, such as the friction-reducing properties of lubricants or simple chemical reactions(Ferguson, 1992, p. 11).

Prescriptive knowledge has the form of techniques or instructions: the archtypical technique is the recipe, which instructs one how to prepare a certain dish. In principle, all techniques are such sets, although vastly more complex and often full with nested do-loops, if-then statements and so on. It is the technique, not the artefact, that is the fundamental unit of analysis in evolutionary accounts of technology. They are sets of executable instructions or recipes for how to manipulate nature, much like Richard Nelson and Sidney Winter's (1982) "routines." When these instructions are carried out in practice, we call it *production*, and then they are no longer knowledge but action. It is comparable to DNA instructions being "expressed."

The instructions in the set I call prescriptive knowledge, like all knowledge, reside either in people's brains or in storage devices. They consist of designs and directions for how to adapt means to a well-defined end, much like a piece of software. They can all be taught, imitated, communicated, and improved upon. A "how-to" manual is a codified set of techniques. An addition to the prescriptive knowledge set of a society would be regarded as an "invention" (although the vast majority of them were and are small incremental changes unrecorded by patent offices or history books).

One feature of any technique is that it cannot wholly be written down, and that there is always an irreducible "tacit" component that cannot be eliminated, requiring the persons executing it to possess some knowledge. Not all techniques are explicit, codified, or even verbalized. But even those that are are rarely complete, and much is left to be interpreted by the user. Thus riding a bicycle or playing a musical instrument consists of neuromuscular movements that cannot be made entirely explicit. It should be obvious that in order to read such a set of instructions, readers need a "codebook" that explains the terms used in the technique (Cowan and Foray, 1997). Even when the techniques are wholly explicit, the codebook may not be, and thus another codebook is needed to decipher the first and so on. Eventually some knowledge must be tacit. Sometimes instructions are "tacit" even when they could be made explicit but it is not cost-effective to do so.

Each society has access to some metaset of feasible techniques, a monstrous compilation of blueprints and instruction manuals that describe what society can do. What these techniques looked like in the more remote past is often hard to pin down. All the same, they existed. From that set, economic decision-makers, be they households, peasants, small-scale craftsmen, or large corporations, selected the techniques actually used. This choice is the technological analogue of natural selection, and since Nelson and Winter first enunciated it in 1982 it has remained the best way to describe and analyze technology and technological change.

Naturally, only a small subset of feasible techniques are in use at any point in time. How society "selects" some techniques and rejects others is an important question that needs to be discussed (Mokyr 2003a). In addition, techniques need to be passed on from generation to generation because of wear and tear on their carriers. Much learning happens within families or in a master-apprentice relationship. Despite the codifiability of many techniques, direct contact between teacher and pupil seemed, at least until recently, indispensable. We need to distinguish between the knowledge needed to write down a set of instructions for the first time ("invent") and carry them out ("produce"). In order to write this paragraph, I have learned to use Word Perfect, but I need not know much about the programming language and technique used by the people who created the software. The amount and kind of knowledge necessary to play the *Hammerklavier* sonata is very different from the knowledge needed to write it.

The role of technology in economic growth

An increase in the set of prescriptive knowledge, allowing society to produce cheaper and better products is at the heart of the economic growth process. Economists have become accustomed to associate long-term economic growth with technological progress; it is deeply embedded in the main message of the Solow-inspired growth models, which treated technological change as exogenous, and even more so in the endogenous growth models. Whether technology is an exogenous deus ex machina that somehow descends like manna from heaven and makes productivity grow a little each year, or produced within the system by the rational and purposeful application of research and development — technology is central to the dynamic of the economy in the past two centuries. The growth of human and physical capital is complementary with growth in useful knowledge, and even the simple TFP computations that often equate the residual with technological progress demonstrate its importance beyond doubt. Many scholars believe that people are inherently innovative and that if only the circumstances are right (the exact nature of these conditions differs from scholar to scholar), technological change is almost guaranteed.

All the same, economic historians studying earlier periods have come to realize that technology was less important than institutional change in explaining pre-modern (say, before 1750) episodes of economic growth. It is an easy exercise to point to the many virtues of "Smithian Growth," the increase in economic output due to commercial progress (as opposed to technological progress). Better markets, in which agents could specialize according to their comparative advantage and take full advantage of economies of scale, and in which enhanced competition would stimulate efficiency and the adoption of best-practice technology could generate growth sustainable for decades and even centuries. Even with no changes in technology, economies could and did grow in the presence of peace, law and order, improved communications and trust, the introduction of money and credit, enforceable and secure property rights, and similar institutional improvements (Greif, 2003). Better institutions could lead to improved allocation of labor and land, encouraged productive investment, reduced the waste of talent on rent-seeking and the manipulation of power for the purposes of redistribution (North, 1990; Shleifer and Vishny, 1998; Baumol, 2002). Pre-1750 growth was primarily based on Smithian and Northian effects: gains from trade and more efficient allocations due to institutional changes. The Industrial Revolution, then, can be regarded not as the beginnings of growth altogether but as the time at which technology assumed an ever-increasing weight and eventually dominant role in the generation of growth.

The main reason why technological progress was at best an also-ran in the explanation of economic growth before 1750 is that even the best and brightest mechanics, farmers, and chemists — to pick three examples — knew relatively little of what could be known about the fields of knowledge they sought to apply. The pre-1750 world produced, and sometimes produced well. It made many pathbreaking inventions. But it was a world of engineering without mechanics, iron-making without metallurgy, farming without soil science, mining without geology, water-power without hydraulics, dye-making without organic chemistry, and medical practice without micro-biology and immunology. Not enough was known to generate sustained economic growth based on technological change.

Around 1750, all this began to change. Economic historians refer to the phenomenon as the Industrial Revolution and locate it in certain regions in Britain in a few key industries such as cotton and iron, but as I have argued elsewhere (Mokyr,2003b), it relates to deeper changes occurring in much of the western world. In any event, the Industrial Revolution marks the beginning of modern economic growth, the kind of continuing expansion that can be sustained decade after decade, and did not run into the blockages and ceilings that previous societies had encountered. The literature on the Industrial Revolution is huge and still growing, and scholars have placed different emphases on economic and social components. The consensus is, however, that it is unimaginable without its technological component. From then on, technological change plays a growing and increasingly pivotal role in economic change, and whereas there can be no dispute that it started in the West, the underlying changes soon were to affect the entire world. What, really, changed?

To understand this profound historical question, we need to make some use of the concepts introduced earlier. The main idea is that in order to manipulate nature, something has to be known about its phenomena and regularities. Each technique in the set of prescriptive knowledge has a support or base in the set of propositional knowledge. I shall call that concept the *epistemic base* of the technique. For purposes of succinctness I shall summarize the logical and historical relationships between the different kinds of knowledge in ten propositions.

1. Every technique has a *minimum* epistemic base contained in the set of propositional knowledge, which contains the least knowledge that society needs to possess for this technique to be invented. The epistemic base contains at the very least the trivial statement that technique i works. There are and have been some techniques, invented accidentally or through trial and error, about whose modus operandi next to nothing was known except that they worked. We can call these techniques singleton techniques (since their domain is a singleton).

2. Some techniques require a minimum epistemic base larger than a singleton for a working technique to emerge. It is hard to imagine such techniques as nuclear resonance imaging or computer assisted design software as emerging in any society as the result of serendipitous finds or trial-and-error methods, without the designers having a clue of why and how they worked.

3. The *actual* epistemic base is equal to or larger than the minimum epistemic base. It is never bound from above in the sense that the amount that can be known about the natural phenomena that govern a technique is infinite. In a certain sense, we can view the epistemic base at any given time much like a fixed factor in a production function. As long as it does not change, it imposes concavity and possibly even an upper bound on innovation and improvement. On the other hand, beyond a certain point, the incremental effect of widening the actual epistemic base on the productivity growth of a given technique will run into diminishing returns and eventually be limited.

4. There is no requirement that the epistemic base be "true" or "correct" in any sense. In any event, the only significance of such a statement would be that it conforms to contemporary beliefs about nature (which may well be refuted by future generations). Thus the humoral theory of disease, now generally rejected, formed the epistemic base of medical techniques for many centuries.

5. The wider the actual epistemic base supporting a technique relative to the minimum one, the more likely an invention is to occur, ceteris paribus. A wider epistemic base means that it is less likely for a researcher to enter a blind alley and to spend resources in trying to create something that cannot work. Thus, a wider epistemic base reduces the costs of research and development and increases the likelihood of success.

6. The wider the epistemic base and the lower the access costs to it, the more likely an existing technique is to be improved, adapted, and refined. The more is known about the principles of a technique, the lower will be costs of development and improvement. This is above all because the more is known why something works, the better the inventor can tweak its parameters to optimize it for different applications and debug the technique. Furthermore, because invention so often consists of analogy with or the recombination of existing techniques, a larger catalog of existing techniques (which is part of propositional knowledge)

and lower access costs to it stimulates successful invention.

7. The epistemic bases in existence during the early stages of an invention are historically usually quite narrow at first, but are often enlarged following the appearance of the invention, and sometimes directly on account of the invention. A new invention which is not properly understood stimulates the curiosity of researchers to try to see why it works and focuses their minds on a specific problem. In this sense, there is positive feedback from prescriptive to propositional knowledge, and it is this positive feedback that turbo-powers economic expansion in a technologically progressive economy.

8. Both propositional and prescriptive knowledge can be "tight" or "untight." Tightness measures the degree of confidence and consensualness of a piece of knowledge: how sure are people that the knowledge is "true" or that the technique "works?" The tighter a piece of propositional knowledge, the more likely the technique is to be adopted, and vice versa. Of course, tightness is normally closely correlated with observables: a laser printer can be easily seen to work better than a dot matrix, and there can be little dispute about the characteristics here. But for many medical and farming techniques it is often difficult to observe what works and what does not work as well without careful statistical analysis or experimentation.

9. It is not essential that the inventor, that is, the person writing the instructions, actually knows him or herself everything that is in the epistemic base. It is enough for the inventor to consult someone that knows – hence the importance of access costs. Even if very few individuals in a society know quantum mechanics, the practical fruits of the insights of this knowledge to technology may still be available just as if everyone had been taught advanced physics. What counts is collective knowledge and the cost of access as discussed above. It is even less necessary for the people actually carrying out the technique to possess the knowledge on which it is based, and normally this is not the case. Instead, each person executing a technique needs to possess a certain *competence*, which consists of the knowledge of how to read and execute the instructions in the technique and the supplemental tacit knowledge that cannot be fully written down in the technique's codified instructions.

10. The existence of a minimum epistemic base is a necessary but insufficient condition for a technique to emerge. A society may well accumulate a great deal of propositional knowledge that is never translated into new and improved techniques. Knowledge opens doors, but it does not force society to walk through them. It is here where the centrality of institutions and their interaction with useful knowledge is paramount.

Given these propositions, we can sharpen our understanding of modern economic growth. The technological breakthroughs we associate with the early stages of the Industrial Revolution (1760-90) could have crystallized into a new more or less static world as had happened repeatedly in the past. The Industrial Revolution would still have taken place in some sense, but it would have fizzled out by 1800 and a new stationary state would have emerged, as most observers at the time expected. This did not happen largely because the epistemic bases of the new techniques were wider, and more importantly, because they were growing. The growth of propositional knowledge after 1750 was of course no accident: technology and science influenced one another in many ways and coevolved, reinforcing and strengthening one another. The traditional linear model in which advances in science led to technological progress has long been abandoned. Technology affected science as much as the other way around. Moreover, as noted propositional knowledge contains a lot more than science and while the hallmark of technological modernity is that the scientific component is large and growing, in the period of the Industrial Revolution it was still quite small. The artisanal and descriptive forms of propositional knowledge were, however, rapidly as well. Dexterous and clever men learned to design better machines, based on principles that were slowly becoming better understood even if the science behind them was still quite murky.

Had the set of propositional knowledge remained more or less static, and had access costs remained the same, the expansion of techniques in the early Industrial Revolution would have run into diminishing returns. We might well imagine a counterfactual technological steady state of throstles, wrought iron, canals, and stationary steam engines, in which there was a one-off shift from wool to cotton, from animate power to stationary engines, and of cheap wrought iron, with no further progress. However, the "first wave" of innovations was followed after 1820 by a secondary ripple of inventions that may have been less spectacular, but these were the microinventions that provided the muscle to the downward trend in production costs. The second stage of the Industrial Revolution adapted novel ideas and tricks to be applied in new and more industries and sectors, improved and refined the earlier and eventually showed up in the productivity statistics. The techniques applied first in cotton were adapted to wool and linen. Iron became progressively better and cheaper. Railroads reduced transport costs and allowed more local specialization and eventually more labor mobility. Iron ships equipped with modified high-pressure boilers began shipping ever-cheaper food and raw materials from other continents. Chemists learned why the old processes worked and then varied them to make the old ones cheaper and create entirely new ones. By 1870 we can speak of a second Industrial Revolution. While income growth in Britain during the "classical" Industrial Revolution had been modest, per capita growth after 1830 accelerates to around 1.1 percent, modest perhaps by modern standards but unprecedented in the nineteenth century.

In the ensuing years, the role of technology in economic growth has been steadily expanding. The second Industrial Revolution added many new ingredients to the ever expanding horizons of production in the west: cheap steel, electrical power, synthetic chemicals, pharmaceutics, food processing, and interchangeable parts manufacturing to mention a few. By 1914, the technological gap between the West and the Rest had reached unimaginable proportions, resulting not just in a large difference in income per capita as far as we can measure it, but also in the ease with which Europe controlled much of the under-developed world.

The economic history of the twentieth century is perhaps the best testimony to the enormous force that growing useful knowledge had acquired as an agent of historical change by 1914. After all, whereas during the nineteenth century (actually between 1815 and 1914) Europe had been relatively at peace and subject to only minor and short-lived fluctuations, the twentieth century was an age of two devastating world-wars, a collapse of the international economy after 1914, violent inflations and a great depression vastly more serious than anything previous experienced, the rise of totalitarian and/or collectivist governments that imposed policies almost always detrimental to economic growth. To top things off, Europe lost its colonies after 1945 and population growth slowed down to a trickle with the decline of fertility in the closing decades of the century. Had an informed observer in 1914 been told of these pending events, a prediction of unavoidable sharp economic decline would have been in place.

Yet despite those obstacles the West experienced much faster growth in the twentieth century than before. We can only guess at how much faster this growth would have been had the fateful events in July 1914 taken a different turn and the world had been spared the horrors of the wars and of Leninism and Hitlerism. What is even more remarkable is that there were few dramatic technological breakthroughs in the decades immediately following 1914: many of the technological advances of the twentieth century were in place in 1914, and just needed continued development and improvement to make their mark on daily life. Internal combustion engines, aviation, telephony, electricity, synthetics, even electronics had their starts in the years before World War I. The following three decades witnessed continuing expansion of these techniques, with dramatic consequences for the standard of living of those lucky enough to survive.

After 1945, dramatic new developments did occur again, especially the advances in microprocessors, unorthodox energy sources and uses, antibiotics, satellites, and a plethora of new materials, to name just a few. Yet here too, what strikes one is the importance of development rather than invention alone. The invention of the laser, to pick just one example, is a dramatic application of quantum physics and would have been probably impossible in the nineteenth century. But its rapid application to areas as diverse as music playing, barcodes, eye surgery, and smart bombs testifies to the wide epistemic base of the knowledge underlying it and the much lower access costs that twentieth century engineers and inventors faced. Not all new techniques were equally successful, and some of them have been abused. Yet the overall picture is undeniable: the growth of useful knowledge and the concomitant technological progress has turned from a relatively small contributor to economic change to the engine that moves economies to ever-higher plateaux.

Institutions, politics and the conditions for knowledge

Technology may have been the engine of economic growth in modern times, but as any driver knows, cars do not move by engines alone. Many scholars feel that *institutions*—formal and informal—matter more: the trustworthiness of government, the functionality of the family as the basic unit, security and the rule of law, a reliable system of contract enforcement, and the attitudes of the elite in power toward individual initiative and innovation. Some societies are simply better organized and their incentive systems work better. In this view, best expressed by North (1990) and Eric Jones (2002), hard work, initiative, and frugality will bring about growth only if they are properly rewarded, and such rewards are determined by the institutional structure. The main institution that accounted for economic success was the market, but I submit to you that markets on their own could not have generated the level of growth we have experienced since 1914.

The juxtaposition of "institutions" and "useful knowledge" as alternative explanations of economic growth is, to a large extent, artificial. Differences in institutions are better at explaining differences in income levels in cross section at a given moment. Knowledge can and does flow across national boundaries, if not always with the frictionless ease that some economists imagine. If the only reason why Germany is richer than Zimbabwe today were that Germany possesses more useful knowledge, the difference might be eliminated in a relatively short time. If we were to ask, however, why Germany is richer today than it was in 1815, the importance of technology becomes unassailable—though better institutions might still be of importance as well.

However, such decompositions of the sources of growth are of limited use. Institutions and knowledge interact, and the interaction term may be larger than the individual components on their own. Institutions play a central role in the rate and direction of the growth of useful knowledge itself. Science and technology, as the constructivist school insists, are social processes. This approach is not as remote from the thinking of economists as they believe: everyone agrees that incentives matter. It is also understood that the supply of talent in the economy is finite, and that it should be regarded as another scarce resource (Murphy, Shleifer, and Vishny, 1991). Institutions help determine on which margins the efforts and time of the most resourceful and ambitious men and women will be applied. Potential entrepreneurs, innovators, and inventors will try to make their fortune and fame wherever they perceive the rewards to be most promising. There are many possible avenues where this can be done: industry, commerce, innovation, the arts, and finance—or plunder, extortion, and corruption. From the point of view of the economic agent a dollar made in any activity is the same. From the point of view of the economy, however, entrepreneurial activity is enriching, rent-seeking is impoverishing (Baumol, 1993). The institutions of society determine where these efforts will be most rewarding and remunerative.

Institutional factors mattered first and foremost because they determined the efficiency of the economy by affecting the exchange relations among people, resource allocation, and savings and investment behavior. Useful knowledge is different. The fundamental nature of production is an attempt to tease out of the environment something that is desirable by humans but that nature is not willing to give up voluntarily. By abandoning hunting and gathering and by exploiting the regularities they detected in nature, people invented farming and created what we might call a production society. By formalizing these regularities into something that eventually became "science" and allowing them to interact with the techniques they implied, the Baconian program reached a critical mass in late eighteenth-century western Europe. There was nothing inevitable about this, and it is far from obvious that, had western Europe never existed, or had it been wiped out by Ghenghis Khan or taken over in its entirety by the Spanish inquisition, that some other society would have eventually developed X rays, solar-powered desk calculators, and freeze-dried coffee.

The search for new knowledge can take many different avenues, some of which are more useful than others. Knowledge that may have seemed initially as rather abstract, such as pure mathematical knowledge, can find eventually unexpected uses. And yet, the accumulation of useful knowledge is not like other entrepreneurial activities. The drive for the understanding of nature and the recognition of one's peers for having done so successfully transcends purely material motives. In all human societies, curiosity and the thirst for knowledge for its own sake have been a driving motive in the accumulation of propositional knowledge. People do not expect to be paid for solving crossword puzzles; they enjoy the challenge. Scientific and technological puzzles are no different. One way of describing the modern age is that the relative importance of knowledge for its own sake has declined relative to useful knowledge that may be mapped fruitfully into better techniques. Whereas some part of the growth of propositional knowledge in a society of market-driven capitalist institutions is still motivated by pure epistemic motives, economic interests, no matter how remote, have become increasingly important in driving and directing the growth of useful knowledge in the past century and a half. The Baconian dream is increasingly becoming a reality.

Moreover, much of the transformation of useful propositional knowledge into techniques comes from discoveries whose significance as an epistemic base was realized only much later. What may seem knowledge acquired for purely epistemic reasons, ends up finding unexpected applications never dreamed of by the discoverers. It would be absurd to think that Niels Bohr and Erwin Schrödinger were thinking of MRIs and lasers when they helped develop quantum physics. Yet such detachment cannot be said to describe "pure" science fully today. Somewhere in the back of the minds of most "pure" scientists are funding considerations. Funding agencies, somewhere in the back of their minds, think of legislators. And legislators, one hopes, in a remote corner of the back of their minds, have society's needs at heart. Much research into prescriptive knowledge, of course, is directly inspired and motivated by the perceived needs of society. No inventor sets his mind in making something that nobody would want. Curiosity, the love of challenge, and other "internal" mechanisms have not disappeared, but they have to share the dominant motivation for research into propositional knowledge with financial considerations as determined by the market.

The existence of organizations in which such knowledge is preserved, diffused, and augmented (such as academies, universities, and research institutes) and the rules by which they play (such as open science, credit by priority, reproducibility of experiment, and rhetorical rules of acceptance) helped determine its historical path. The rate of technological development has been deeply affected by the fact that the people who studied nature and those who were active in economic production have been, through most of history, by and large disjoint social groups. The flows of knowledge between them and the ease of access to social stores of knowledge were of central importance in explaining progress over past centuries.

Access was important because useful knowledge could only become economically significant if it was shared, and access was shaped by institutions, attitudes, and communications technology. Today, far more than in the past, those who create new techniques and products have the training and the wherewithal to give them easy access to the propositional knowledge that serves as the epistemic base for the new prescriptive knowledge. The miracle of modern economic growth cannot be understood without a clear understanding that the modern age is different in this respect.

How this transformation occurred is a complex tale, to which no justice can be done here. In the middle of the seventeenth century most of what was to become the industrialized West was still in the grips of mercantilism, which regarded economic activity as a zero sum game in which whatever one nation or one group within that nation could wrestle away from others was their net gain. The notion that such redistributive or "rent-seeking" activities were bad for society still had not ripened. It is only during the Enlightenment that it slowly dawned upon Europeans that the search for useful knowledge was one of the keys to the continued economic and social progress they sought. This movement within the Enlightenment traced it origins back to Francis Bacon and insisted that the social agenda of research take into account the potential of natural philosophy to improve the "useful arts" – that is, technology.

For such progress to take place, a number of things had to happen. One was that society would ensure that whatever gains resourceful innovators and manufacturers made of their technological advances would not be expropriated by criminals, foreign invaders, tax collectors, or personal-injury litigators. Rent seeking had to be constrained, and this point became a major item of concern among Enlightenment thinkers, above all Adam Smith. Secondly, social institutions had to restrain political forces that opposed technological innovation and the expansion of useful knowledge. Such resistance might originate from vested interests trying to protect their turf, from conservative ideologues, or from concerned citizens who fear that unknown techniques might incur unforeseen and unsuspected costs that dwarf their benefits. In any event, without institutions favorable to innovation, technological progress might be seriously impeded and even completely stopped in some areas. Furthermore, it is frequently maintained, society needs a certain degree of individual freedom to achieve technological progress. Historically, this is less obvious than it might sound. Technological progress occurred in many places that do not seem free, at least by our standards. What may be more important than "freedom" is a certain tolerance for rebels and deviants, who are dissatisfied with current states of knowledge and think they can do better. It bears keeping in mind that most of such rebels never discover or invent anything useful and become little more than a nuisance to others. It is a small proportion of them who become the Galileo's, Lavoisiers, and Faradays. But *ex ante* it is impossible to know who among them will make important discoveries, so the unavoidable price society pays for technological progress is to put up with troublemakers and crackpots.

Finally, society has to set up positive incentives for creative individuals Some of the best recent work in the economic history of technological change focuses on the working of the patent system as a way of preserving property rights for inventors. In a series of ingenious papers, Kenneth Sokoloff and Zorina Khan have shown how the American patent system exhibited many of the characteristics of a market system: inventors responded to demand conditions, did all they could to secure the gains from their invention and bought and sold licenses in what appears to be a rational fashion. It was accessible, open, and cheap to use and attracted ordinary artisans and farmer as much as it did professional inventors and eccentrics (Khan and Sokoloff, 1993, 1998, 2001; Khan, 2002).

Whether this difference demonstrates that a well-functioning system of intellectual property rights is truly essential to the growth of useful knowledge remains an open question. For one thing, the American system was far more user-friendly than the British patent system prior to its reform in 1852. Yet despite the obvious superiority of the U.S. system and the consequent higher propensity of Americans to patent, there can be little doubt that the period between 1791 and 1850 coincides roughly with the apex of British superiority in invention. The period of growing American technological leadership, after 1900, witnessed a stagnation and then a decline in the American per capita patenting rate. Other means of appropriating the returns on R&D — above all first-mover advantage — became relatively more attractive. In Britain, MacLeod (1988) has shown that the patent system provided only weak and erratic protection to inventors and that large areas of innovation were not patentable. Patenting and intellectual property rights were associated with commercialization and the rise of a profit-oriented spirit, but their exact impact on the rate of technological progress is still obscure.

What is sometimes overlooked is that patents placed technical information in the public realm and thus reduced access costs. Inventors, by observing what had been done, saw what was possible and were inspired to apply the knowledge thus acquired to other areas not covered by the patent. In the United States, *Scientific American* published lists of new patents from 1845, and these lists were widely consulted. Despite the limitations that patents imposed on applications, they reduced access costs to the knowledge embodied in them. This function of the patent system apparently was fully realized in the 1770s. The full specification of patents was meant to inform the public. In Britain this was laid out in a decision by chief justice Lord Mansfield, who decreed in 1778 that the specifications should be sufficiently precise and detailed so as to fully explain it to a technically educated person.

Patenting is not the only mechanism that has historically been used to reward inventors for their efforts and make sure they reap the fruits of their work and investment. In propositional knowledge, indeed, IPR's are not used and explicitly eschewed. Inventions can be patented, discoveries cannot. The norms of "open science," established in Europe during the Scientific Revolution, meant that contributions to propositional knowledge were placed in the public realm as soon as they were made. The recognition of a property right in an idea meant a citation, but no more. Academics get very obsessive about citations to their work, and this is precisely the cause. Those who made discoveries that were regarded as particularly useful were rewarded in a variety of ways: medals, pensions, life-long tenured jobs, honorary doctorates, aristocratic titles, and prizes (including the Nobel prize in our time). There is no suggestion that there is any proportionality between the magnitude of these rewards and the economic value of the addition to propositional knowledge. Perhaps there should not be: it is society at large that appropriates most of the surplus of new knowledge. All the same, the rate of growth of useful knowledge is sensitive to the incentives to which creative individuals are subject, because on the margin individuals make decisions on how to spend their lives and what careers to pick.

Useful knowledge and changes in daily life

Knowledge matters not only to production. What people know — or, more accurately, what they *think* to be true — matters a great deal to daily life. Households allocate resources to purchase goods not just on the basis of preferences, income and relative prices. They also have certain beliefs about their environment and physical world which helps make decisions as to how to consume. A medieval farmer might have paid a priest whose prayers, he believed, would increase his crop. Rhinoceros horn is eagerly purchased by some people who believe it to be an aphrodisiac. On the whole, however, until recently, consumption was not affected much by knowledge of the human body because the understanding that what people eat and how they look after themselves and others determines their health required knowledge that was simply not there. Most people were fatalistic about sickness and death and believed it beyond their power to prevent it from happening. Though *some* ideas that dirt was unhealthy and that spoiled foods could make one violently sick had been around since antiquity, these ideas were developed and became far more accepted in the last third of the nineteenth century. It became, perhaps, the greatest revolution that more and better knowledge ever produced.

The basic idea I want to propose is that consumers choose consumer goods in part on the basis of their beliefs as to how consumer goods affect their health. This has had major consequences in human history. What counts, above all, is what people believe to be true about the material world around them and how their actions and the way they run their lives affect their physical state. Nobody can fully understand the complete impact of consumption on their health, because the human body is an unbelievably complex entity, which interacts at many level with its environment. People can, however, be closer to or further from the truth (or what appears to us to be the truth) in measurable amounts. The household choices regarding matters that affect their health depend in part on what they know, of course, but there must be more to it than that. As biologist Richard Lewontin has observed, "the reason that people do not have a correct view of nature is not because they are ignorant of this or that fact about the material world but that they look to the wrong sources in their attempt to understand it" (1997). The point, however, is that one can follow better recipes even on a narrow epistemic base, that is, without having a "correct view of nature," as long as one is willing to accept techniques and rules of thumb designed by authorities and trusted experts, if these actually improve health. In that sense the notion proposed above regarding the social character of the epistemic base of techniques applies. Homemakers do not have to know in any detail *why* certain kinds of prescriptive knowledge work, they just have to be persuaded to follow the instructions.

How do households pick and choose from the vast menu of commodities and recipes those that they believe enhance their health? Best-practice medicine, bacteriology, physiology, and nutrition science (to pick just a few) of course play a major role. But households are not like firms: no competitive pressures "force" them to adopt best-practice techniques. Someone had to persuade them. Rhetoric, marketing skills, political influence, and prejudice, as well as emulation and social learning, came into play. Persuasion requires shared standards of evidence, chains of authority, networks of trust, and accepted rules of logic and evidence. Changes in the rules of discourse and communication, the nature of authority and expertise, no less than the knowledge itself unearthed by science, were the background to the changes in health and longevity that are the mark of the "modern" age.

The sources of the growth in this knowledge can be readily identified. One was the growing use of statistics (in the sense of large databases) to identify patterns and regularities. The roots of this movement went back to the eighteenth century, especially to the debates around the efficacy of the smallpox inoculation procedure, the beneficial effects of breast-feeding, and the bad effects of miasmas (putative disease-causing elements in the atmosphere). But only in the second third of the nineteenth century did this movement truly take off. The founding of the Statistical Society of London in 1834 led to an enormous upsurge in statistical work on public health. In Britain, William Farr, William Guy, and Edwin Chadwick were the leaders of this sanitarian movement, but it encompassed many others (Flinn, 1965). On the continent, the leaders of the statistical movement included such notables as Adolphe Quetelet, René Villermé, and Charles-Alexandre Louis clustered around the *Annales d'hygiène publique* in the 1830s. The connection between the sanitarian movement and the statistical revolution was fundamental to the changes in the perceived health effects of consumption and behavior. Between 1853 and 1862 no less than a quarter of the papers read before the Statistical Society of London dealt directly with public health and vital statistics.

Among the other great triumphs of this methodology were the discoveries of John Snow and William Budd in the 1850s that water was the transmission mechanism of cholera and typhoid, and in 1878 that milk was a carrier of diphtheria by correlating the incidence of the disease with milk-walks (Hardy, 1993, p. 90). In clinical medicine, the use of statistical tools was critical to the insight of C. A. Louis, who developed a "numerical method" for evaluating therapy and around 1840 provided statistical "proof" that bloodletting was useless, leading to the gradual demise of this technique (Hudson, 1983, p. 206). Louis's work and the decline of bloodletting was an excellent example of how statistical methodology could make propositional knowledge tighter and subsequently persuade others to change their techniques. Similar work on breast-feeding led to a campaign to persuade women to nurse longer. Statistical analysis — using more sophisticated techniques and huge databases — still underlies much work on the impact of consumption on health in our own time, from the effects of smoking to those of breastfeeding and fat consumption. Such quantitative studies are a substitute for a true epistemic base: it is exactly because we do not understand precisely how broccoli or garlic prevent colon cancer that we need to rely on large scale statistical studies to persuade us to change our diets.

The second breakthrough of the nineteenth century, was the germ theory of disease. Bacteriology was more than just a way of attributing certain symptoms to certain microorganisms. The germ theory provided an entirely new concept of disease: how it was caused, how to differentiate between symptom and cause, and how infection occurred. As is well known, the germ theory was not quite "invented" in the decades after Pasteur's famous work on silkworm disease. It had been proposed repeatedly since the sixteenth century, and in 1840 Jacob Henle revived the theory in Germany. It remained, however, on the fringes of medical science, and in the following decades Henle was regarded by the medical profession as fighting a "rearguard action in defense of an obsolete idea" (Rosen, 1993, p. 277). We might say that the germ theory prior to Pasteur and Koch was *untight*. It might be true or it might not, but for contemporaries there was no way of knowing for sure. The triumph of the germ theory after 1865 should be regarded above all as a victory of scientific persuasion in which brilliant scientists were able to combine scientific insights with considerable academic prestige and a good understanding of how power and influence work in the scientific community (Latour, 1988). It relied on an experimental method widely touted to be a failsafe way of unearthing "truth" and was thus accepted by increasing numbers of people with the same blind faith previously reserved for religion. Rhetorically, then, it was useful knowledge that was powerful and persuasive enough to change the recipes used by households in the West even if many of the details of the new theory of disease remained highly controversial for decades.

The third revolution consisted of the knowledge that small traces of certain substances are crucial to human health. The realization that some crucial substances cannot be manufactured by the body from other nutrients and need to be supplied by the diet is of special interest here, because normally these techniques involved relatively minor and inexpensive reallocations of household resources with disproportionate favorable effects. It may seem that once this knowledge was discovered, the mapping of this knowledge to household techniques would have been obvious and immediate, and changes in behavior would be forthcoming rapidly. But historically this was not quite the case. Physicians in the West had discovered in the nineteenth century that cod liver oil was an effective treatment for rickets, but this was a purely empirical procedure, a typical singleton technique not based on any notion of why it worked (Rosen, 1993, p. 383). Hence mistakes were made and further development was blocked, as was often the case with techniques that rested on a narrow epistemic base. Another example is the history of scurvy. The importance of fresh fruit in the prevention of scurvy had been realized even before James Lind published his *Treatise on Scurvy* in 1746. The Dutch East India Company kept citrus trees on the Cape of Good Hope in the middle of the seventeenth century, yet despite the obvious effectiveness of the remedy, the idea did not catch on and "kept on being rediscovered and lost" (Porter, 1995, p. 228). Only after the seminal paper by Axel Holst and T. Fröhlich in 1907, which reported the inducement of scurvy in dietarily deprived guinea pigs, did it become clear that certain diseases were not caused by infectious agents but by deficiencies of trace elements, and only in 1928–32 was ascorbic acid isolated as the crucial ingredient (Carpenter, 1986; French, 1993). Before the epistemic base of nutritional deficiency diseases was recognized and became tight, the techniques dealing with these diseases were simply pathetic.

In this fashion, new knowledge affected daily life. People learned to make sure to drink safe water, to take better care of their babies, to avoid lice and mosquitoes, to eat fresh vegetables and fruits, to wash themselves and their utensils, and so on. Humanity had discovered that microbes around them threatened their lives and while they could still not cure these diseases when they occurred, they learned how to avoid them by "tweaking" their consumption, buying more soap and grapefruits. For this to occur, of course, they had to be persuaded that this was in their interest.

The prestige and authority of learned men and women in white coats increased steadily in the late nineteenth and twentieth centuries, and an entire discipline arose ("domestic science" or home economics) whose purpose it was to instruct people in the healthy and responsible ways of running a household. A main function of medical professionals – who still made house calls in those days – was to instruct and inform the population of the "correct" procedures. They were assisted by such organizations as the British Ladies' National Association for the Diffusion of Sanitary Knowledge (founded in 1857). Between 1857 and 1881 this association distributed a million and a half tracts loaded with advice on pre- and postnatal care, made millions of house visits, and spread the gospel of soap and clean water. In the late Victorian period, the poorer classes were apparently receptive to these volunteers (Wohl, 1983, pp. 36–37). The association also published tracts on diet and either taught cooking classes or campaigned to have it taught in elementary schools (Williams, 1991, p. 70).

The effects of this revolution were massive and can be summarized under the following headings.

1. **Longer lives.** Life expectancy increased enormously in the seventy years before the invention of antibiotics, mostly due to the decline in infectious disease. Between 1900 and 1950 most Western societies experienced a gain of about 25 years, a historically unprecedented event. Since clinical treatments for most of these diseases were still largely unavailable, it must be chalked up primarily to preventive treatment and public health.
2. **Better lives.** Data on morbidity are more difficult to find but not altogether absent. By avoiding diseases – especially childhood diseases – people lived healthier and better quality lives. One corollary of this is the increase in the physical stature of Western people, for centuries stunted by childhood diseases and malnutrition.
3. **Changing Role of Government.** It became clear that certain forms of disease prevention could only be carried out effectively by the public sector, especially in the areas of sanitation and insect control. This led to a considerable increase in government intervention, widely regarded as benign by most economists. At times the government felt it knew better than its own citizens what was good for them, adding chlorine and later fluoride to drinking water, and Vitamin D to margarine (a policy that eliminated rickets).
4. **Changing roles of women.** Much preventive medicine depended on cleaning and other forms of household labor. Traditionally, these tasks had been carried out by women, and the sanitary and nutritional revolutions made women the foot soldiers of the movement. This redefined the role of women as the sanitary guardspersons of the household and created a serious impediment to their employment outside the household until the second half of the twentieth century.
5. **Changing role for Science** There can be little doubt that the improvement in health and life expectancy have contributed enormously to the prestige and authority of science in the modern world. Far more than the discoveries of quantum physics, relativity, genetics, and other major scientific achievements of our century, this revolution has been responsible for the crowning of scientists as the new oracles of our modern society. Experts and trained professionals are now expected to solve our problems whatever they are, much as priests were in earlier times. The successes of social science, economics, psychiatry, and psychology in affecting our daily lives, such as they are, cannot really compare with the dramatic increase in the physical characteristics of life.
6. **Social Security**. The increase in life expectancy has created, for the first time in history, a new leisure class of pensioners. Leisure classes in previous ages were always the rich and

powerful; the poor normally worked until they dropped, and few workers lived much beyond their productive years. The twentieth century has made it possible to create a wide-spread phenomenon in which the majority of people can live beyond the age at which they can usefully work. Thus new knowledge has created, indirectly, a new economic and social phenomenon whose full implications are apparently not yet fully understood.

The diffusion and migration of knowledge

As noted above, the impact of knowledge is proportional not only to its content but also to its diffusion. Knowledge dissemination takes place at both the international and the local levels. The fundamental fact that dominates the literature on this topic is that knowledge is almost always costly to acquire, but it is a public good in that someone who possesses it and shares it with another — unlike pizza or land — does not have less of it him or herself, a property known as non-rivalrousness. Moreover, in many cases it is difficult to exclude others from access to knowledge. To be sure, secrecy and intellectual property rights can to some extent exclude from knowledge, but once the knowledge has been imparted to another, it is hard for the original owner to prevent it from flowing to third parties.

A very naive question would be this: if useful knowledge is the central factor in economic growth and if it is a public good that can flow at low cost from developed countries to the third world, why isn't the whole world developed (Easterlin, 1981)? As I noted above, economic performance depends on institutions that will actually allow an economy to take advantage of whatever knowledge it has. It is therefore perfectly imaginable that if Iraq and Denmark have access to the same knowledge, they would still have very different economies.

Yet knowledge is not equally shared amongst different economies in the world, and understanding why may enhance our understanding of how knowledge affects the economy.

1. **Human Capital**. A great deal of useful knowledge – both propositional and prescriptive – requires substantial training to acquire. It is often written in technological jargon and demands heavy investment in prior education. In countries in which these skills are scarce, knowledge can only be imported together with foreigners who possess it. Yet upon closer examination this issue seems to be less important than is often believed: many poor countries have good institutions of learning (e.g. the Indian Institute of Technology) and yet the graduates of these schools seem to have a low social marginal product and often emigrate to Western countries. If they were truly indispensable, their countries would make more of an effort to keep them. Moreover, many residents of these countries have opportunities to study in the West. Had this been the sole bottleneck, a massive education effort would be able to solve much of the problem in a fairly short time.
2. **Physical Capital**. Technology is knowledge, but often it requires implements or artefacts to be actually executed. No knowledge of playing a piano will be of much use in the absence of the instrument. Advanced equipment and knowledge are typically highly complementary, and if such equipment is too costly in a particular society, there seems to be little point in acquiring the knowledge. Poor nations that cannot afford, say, sophisticated MRI machines would be ill-advised to send their doctors to study how to use these machines.
3. **Bad Policies**. Institutions affect economic performance directly, but they also feed through useful knowledge. Governments play, as I already noted, an important role because

knowledge as a commodity cannot rely on market mechanisms alone. Governments must invest in infrastructure for knowledge to be diffused: libraries, communications networks, and the like. Moreover, governments must create the conditions for knowledge transfer. These can be quite different than knowledge *creation*. Knowledge diffusion requires a willingness to learn, to follow, and to imitate. After the Meiji revolution in Japan, this is precisely what the Japanese authorities did and the Chinese did not. It involves an implicit admission of the technological superiority of foreigners (in some dimension at least), which can be hard on the national pride. It also may conflict with local ideology or religion: it is often asserted, for instance, that some Islamic societies tend to be hostile to Western science. Moreover, it may well be that the correlation of this knowledge with the West may create a hostility toward it for political reasons that have little to do with the content.

4. **Competence and Knowledge** The fundamental reason, however, why not all useful knowledge is spread equally among nations is that it may actually matter less to economic development and performance than is commonly believed. The reason I believe so goes back to the very definition of production: production is the execution of a technique. It is, as I noted, not important for the person who carries out the technique to possess the epistemic base of the underlying instructions. He/she does not have to understand how and why a technique works the way it does. All he/she has to know is how to carry them out. This knowledge is what I call competence and its relationship with useful knowledge is actually quite complicated. It is quite possible for techniques to become increasingly sophisticated, relying on increasingly wide and diverse epistemic bases, and yet to require less and less competence because they are more standardized and user friendly. This implies, in fact, that much of the knowledge in this world that drives continuous economic growth is normally concentrated in the minds of a relatively small number of better and better trained people, but that for the vast bulk of workers this knowledge is not necessary. African nations can use cell phones and airplanes well without having the sophistication of the engineers of Nokia and Airbus and anti-AIDS medications without having to develop them from scratch. At first glance, there is no real down-side to this: an international specialization in knowledge is inevitable in any case. Nobody expects Luxembourg to develop their own knowledge of airplane construction, for them that of Boeing is quite sufficient.

A corollary of these propositions is that the uneven diffusion of knowledge among different societies is not the main cause of the huge and growing differences in income and living standards between developed and underdeveloped countries. There is not much in Western science and technology that Liberian or Haitian engineers could not learn in a relatively short time, if perhaps assisted by spending a few years at MIT or CalTech. But on its own, such knowledge would not help these countries bridge the gap; all that would happen is that such highly trained people would search for jobs in richer countries and not go back to their home countries. Instead, the economic conditions for production using sophisticated and interdependent techniques have to be met: stable and honest government, law-and-order, competent, reliable, and compliant workers, and similar normal requirements for a prosperous society. If these are met, all that counts is access costs to the knowledge that is already there. Given the recent sharp fall in the marginal access costs to much of this knowledge, this does not seem to be too high a hurdle.

Intellectual Property Rights. The one obstacle to the use of prescriptive knowledge in countries that may be behind in their propositional knowledge is IPR's. Corporations that spend large sums on R&D that yield successful prescriptive knowledge are understandably unlikely to make it freely available to possible users and while they hold patents tend to charge high prices for the knowledge. The economic quandary is well-known: once the knowledge exists, it is costless for the owner to share it, but of course this will erode a monopoly position that may have been the incentive to create the knowledge in the first place. Most economists seem to regard some profits to those who create prescriptive knowledge as the inevitable cost of progress. It surely is possible to regulate and modify such profits by economic policy. The drug companies that created antiviral drugs, at possibly very high cost, should sell at prices very different from those charged for good with lower net social utility. Simple policy measures in the knowledge-creating countries could resolve this issue fairly easily, but relying on free markets alone may not do the trick.

Is Knowledge "good?" Some ethical considerations.

Economists today are usually bad philosophers. The age of giants trained in philosophy such as Adam Smith, Karl Marx, and John Stuart Mill, is long passed. For most people trained in economics, the simple idea that "more is better" derived from Benthamite utilitarian calculus seems to be enough. It is better to have more than less, and welfare comparisons are based on that axiom. Distributional issues are of course discussed, but often in terms that look at the effect of redistribution on the total size of the pie. With the issue of useful knowledge as defined here, the matter does get more complicated and it is important to at least place the issues on the table.

Is more knowledge always better? In general, the answer must be no: everyone can think of a possible set-up in which an individual can be made worse off by revealing some damaging fact. But in this paper I have defined useful knowledge in a far more limited way namely as that subset of all knowledge that deals with the understanding of nature for the purpose of controlling and manipulating her for our material benefit. Can such knowledge ever be bad? It is obvious that in the past people have clearly believed so. Prometheus, who revealed to mankind the Gods' secret of fire was punished for his deed, and humanity itself was punished by unleashing Pandora's box. The famous myth of the Sorcerer's Apprentice symbolizes the dangers of mankind acquiring knowledge not meant for it. Frankenstein-type of stories are all over the literature and reveal a genuine and sincerely felt concern. The current world, despite its seeming sophistication, is not really very different: the resistance to cloning and stem-cell research in the US and to genetically modified foods in Europe reflects these attitudes.

The history of the twentieth century bears out some of those fears. The new useful knowledge acquired in the West during the second Industrial Revolution was used in terrible ways during the two World Wars, culminating in the use of weapons of mass destruction. Many new techniques have had mixed track records in terms of their overall social benefit: internal combustion engines, nuclear power, insecticides and other techniques of environmental control, chlorofluorocarbons, and many other techniques have ex post have involved costs far higher than anyone suspected. The difficulty is not just that some of these techniques have had a negative effect on economic welfare. The problem is the irreversibility of new knowledge. Once it exists, it can almost never be "undone." It may well be that we might be better off in 2003 if nuclear power had never been discovered at all, but that option no longer exists. Much of the political world we live in today is shaped by concerns about the proliferation of knowledge that can be abused by irresponsible governments. It has become obvious that preventing the flow of knowledge to such governments is in the long run a hopeless task, so other measures have to be taken.

In the end, we return to Adam and Eve: what are the ethical implications of useful knowledge? Thanks to useful knowledge, homo sapiens is the most successful species on this planet, dominating and to a large extent controlling the environment. Most other species — not counting insects and rats — exist because humans want them to and countless others will go extinct if homo sapiens wills it. The past two centuries have created material conditions never experienced in history. Middle class people in industrialized countries experience levels of material comfort not even dreamed of by the Pharaohs and Popes of the past. Access to knowledge and art is unprecedented and is getting better at an exponential rate (what, really, did we do before Google?). Infant and child mortality have declined to levels that are as close to zero as they could be. At the same time, mankind is capable of actually wiping out all life on this planet through nuclear weapons and is affecting long-term atmospheric parameters through normal economic activity. Would we better off if we knew less, or at least if we acquired knowledge less rapidly?

The hard fact is that some types of new knowledge will advance whether we like it or not, and that repressive policies that try to prevent its emergence will in all likelihood produce societies that are even worse. Governments that believe that they can stop stem-cell research or cloning by legislating or by denying them funds will be disappointed; off-shore research will eventually produce the new knowledge if there is money to be made. Short of introducing a totalitarian state and suppressing the market economy altogether, the capitalist system cannot be prevented from producing new knowledge if it is feasible and if most of the economic gains can be captured in some fashion by the developers.

Where governments have an opportunity to affect outcomes through policy is in those parts of useful knowledge where the market mechanism does not work well and the outcome is ambiguous. It seems unlikely that private enterprise would ever have produced hydrogen bombs or nuclear reactors without government policies. Yet it did produce lead-based paints, asbestos, thalidomide, and may well be able to produce VX-chemical agents or anthrax and sell it to an affluent terrorist. Neither the private nor the public sector have spotless track records here. Market economies on the whole are rarely destructive per se, but they are capable of making dreadful errors in the blind pursuit of profit and disregard for the interests of others. Lenin was not too far off the mark when he remarked that capitalism would sell the hangman the rope used to hang it. Yet it is governments that have created weapons of mass destruction, that have created the worst environmental disasters, and that have abused useful knowledge in the worst ways. As always, mankind has to stumble and fumble its way through second-best options, hoping to avoid a Chernobyl on a planetary scale or a manmade pandemic on the scale of the Black Death .

Yet if knowledge is full of dangers and pitfalls, so is ignorance. As I have already noted, the twentieth century has been an astonishingly successful century in terms of the improvements in the human lot. We are not individually better people, certainly not smarter, wiser, more judicious, or more moral. But as a collective, mankind in 2003 knows more than ever before and is still learning rapidly. Such knowledge has enormous potential to make life better on this planet, or it has the potential to extinguish it. It seems to me that by knowing more rather than less, the likelihood of a disaster can be limited and any costs incurred by knowledge that misfires can be reduced. Modern technology produced not only the CFC's that threaten the ozone layer of the atmosphere, it also provided Molina and Rowland with the tools to detect the danger and the know-how to come up with substitutes. It is only thanks to the insights of modern microbiology that we have been able to identify the cause of the AIDS epidemic and produce medications. Had the disease occurred, say, in the middle of the eighteenth century, mankind would have had no clue as to how to combat it (in fact, it might never have discovered that it was a STD). Global warming, similarly, has been identified through careful measurement, modelling, and statistical analysis, and its causes are by now increasingly well-understood despite the complexities involved. Useful knowledge based on wide epistemic bases has the miraculous ability to continuously adjust, improve, and self-correct. A wise historian of technology once formulated what has become known as Krantzberg's Law: Technology is neither good nor bad. Nor is it neutral. The same might be said about useful knowledge in general.

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