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Does Knowledge Make History?

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Introduction

Much of economic analysis, including economic history, focuses on technology rather than knowledge. Technology is, in Marx's terms, the means of production. But technology is derived from or based on knowledge. Knowledge is the meta-resource that is used to create technology that enables the use of other resources. Because knowledge is the meta-resource that leads to technology, it is a more foundational category than the latter.

This, however, does not mean that technology is an epiphenomenon, or merely a by-product of knowledge. Technology does interact or interconnect with knowledge, as in the way that the results of practice (technology) can have a feedback effect and amplify knowledge itself. This leads to non-linearity in the relationship, with knowledge both resulting in technology and, through the reverse interaction or feedback loop, enhanced knowledge as also the outcome of the process of interaction.

In this interaction of knowledge and technology, however, over the historical long-run, knowledge is the prime mover that that leads to new techno-economic paradigms that characterize the ages of human history - because the appearance of radically novel technologies, depends on "the constant capture of new natural phenomena and the harnessing of these for particular purposes…Technology builds out not just from combination of what already exists but from the constant capturing and harnessing of natural phenomena" (Arthur, 2009:22). The capturing of natural phenomena goes all the way from using the heat of fire to the steam engine and quantum phenomena. For this

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[1] As a Visiting Scholar at the Robert Heilbroner Center for the Study of Capitalism at the New School for Social Research, it is only apt that the title of this paper is derived from Heilbroner's famous paper "Do Machines Makes History?" (1967).

[2] Institute for Human Development, Delhi; Heilbroner Center at the New School for Social Research, New York; and Southern Centre for Inequality Studies, WITS University, Johannesburg. Govind was joined by Pallavi, in discussing much of this paper with many suggestions and disagreements, particularly on AI. Thanks also to Will Milberg and Padmini Swaminathan for critical comments. I was able to give a lecture based on this essay to economics students at the Symbiosis School of Economics, Pune. Thanks to the students who asked a number of questions and to Jyoti Chandiramani, Dean of the Symbiosis University, for providing the opportunity to see whether I could place this analysis before undergraduate and graduate students.

reason, advances in radically novel technologies, those that have produced the different ages of human history, depend on the advance of scientific knowledge.

At any one time, the set of possible technologies is larger than the set of existing technologies (Kauffman, 2000). Some possible technologies may not have been explored because there was no social need for them. Further, not all knowledge, when formulated, can be turned into technology. There are the famous examples of Leonardo da Vinci's drawings of a helicopter and of a mechanical computer, which recent reconstruction has shown to be functional (Russell and Norvig, 2025: 24); Charles Babbage's design of an automatic calculating machine, or Ada Lovelace's software or mathematical algorithm for calculation on Babbage's imagined machine. These are examples of knowledge that could not be turned into technology because appropriate production capabilities did not exist at the time. In these ways, knowledge does not equal technology. But technology is based on knowledge, even if that knowledge is prescriptive and not propositional.

Although the title refers to history without qualification, it is necessary to clarify what will be dealt with: economic history. History includes much more than the economic, but this paper will not address the social, political, psychological, or military aspects. There are connections between economic and other aspects of history, but that is not something that will be dealt with in this paper, except to draw a connection between knowledge and military history in the period leading to European colonization of much of the world. In another paper (Nathan, forthcoming), I examine the connection between US domination of the world of scientific knowledge, domination of the period's technological knowledge, and its hegemonic role in setting the rules of global capitalism over the past 80-odd years.

This essay is not an analysis of the history of the evolution of knowledge, such as in Juergen Renn (2020). This is an analysis of the impact of knowledge on human history, as a prime cause of major historical changes, such as those the Stone Age, Iron Age, Industrial Revolution and the coming Age of AI. There are other major historical changes, such as of the Bronze Age, which are not dealt with in this essay, mainly because of my own insufficient study of these developments. It should, however, be possible to adopt the approach of this essay to other such major historical developments.

A Summary Analysis of Knowledge and History

Knowledge makes history as humans use their knowledge to create technologies. A historical epoch is characterized by the general-purpose technology or critical technology of that epoch. Thus, we have the Stone Age, Bronze Age, Iron Age, and the machine age (of the Industrial Revolution), to name a few.

There are two forms of knowledge: (1) propositional knowledge or the 'why' of knowledge, and (2) instructional or prescriptive knowledge, the 'what' and 'how' of knowledge (Mokyr,

2002). This parallels the distinction between theoretical and practical knowledge. Knowledge may not always be propositional knowledge ('why') but instructional or prescriptive knowledge ('what' and 'how'). The former is used to create the latter, that is, knowledge of technology or techniques (Mokyr, 2002); but the latter may also develop in advance of the former. However, there is a strong complementarity between the two systems of knowledge, propositional and prescriptive. This possible connection between propositional and prescriptive knowledge can create a feedback loop that keeps increasing knowledge. In the historical process, other feedback loops also exist, such as between increased brain size and accumulated knowledge.

But the advance of knowledge also requires that there be challenges to accepted theories in a manner akin to Thomas Kuhn's analysis in *The Structure of Scientific Revolutions* (1962), whereby old theories or paradigms are replaced by new ones, a process that itself depends on adopting a cosmopolitan attitude towards acquiring knowledge from other, newer, and more diverse centres and standpoints. The absence of critical attitudes to all existing paradigms and of feedback effects between the theoretical and practical circuits of knowledge may both inhibit the development of knowledge and the deployment of technology in production.

Any empirical formulation is subject to falsification (Popper, 1959). Consequently, knowledge systems will necessarily change and cannot be held immutable or required to conform to religious or political tenets. This also means there is no 'final truth', only 'less false' accounts (Harding, 2013). Thus, there should not be religious, state, or even peer authorities' dicta preventing the incorporation of counter-results, the overthrow of older paradigms or any claim to have discovered 'the truth'.

However, knowledge formation also depends on social factors. This social dependence means that those with different standpoints might develop different forms or aspects of knowledge (Harding, 2013).

In addition, "Men make their own history, but they do not make it as they please; they do not make it under self-selected circumstances, but under circumstances existing already, given and transmitted from the past," (Marx, 1852). This means that there is also a path dependence in the development of knowledge or technology. As Heilbroner put it, "I do not think it is just happenstance that the steam-mill follows, and does not precede, the hand-mill, nor is it mere fantasy in our own day when we speak of the coming of the automatic factory" (1967: 340).

To summarize: knowledge is the basis of technology or the productive forces or means of production. The analysis which we have and which I will use of the connection between knowledge (or the forces of production) and the economic organization of society (or relations of production) is the well-known statement of Marx in Preface to A Contribution to the Critique of Political Economy (1859): "At a certain stage of development, the

material productive forces of society come into conflict with the existing relations of production or—this merely expresses the same thing in legal terms—with the property relations within the framework of which they have operated hitherto. From forms of development of the productive forces these relations turn into their fetters. Then begins an era of social revolution. The changes in the economic foundation lead sooner or later to the transformation of the whole immense superstructure."

This will be modified as follows: Knowledge creates technologies, or productive forces, that come into conflict with existing relations of production (the ways in which means of production are accessed and incomes earned); social revolution then transforms the relations of production. The driver in this historical change is that of knowledge and the creation and adoption of technologies. In this essay we will deal with the transformation of the relations of production, or of the techno-economic paradigm (Carlota Perez, 2002), leaving aside Marx's claim about the transformation of "the whole immense superstructure," which will also include political, social, and gender relations, cultures and beliefs. Our concern is with the impact of knowledge leading to technologies, or means of production, on the creation of relations of production and distribution, what might together be called the mode of production, or techno-economic paradigm, and changes in them, as history.

In history, one can look at the role of knowledge in driving the major changes in the world economy, for instance, those of the Stone Age, the Neolithic Revolution and the Industrial Revolution. These are some of the major transformations of the world economy. But within a major transformation there may also be relatively minor changes. For instance, within capitalism there are technological ages, or techno-economic ages, each with its own economic paradigm (Perez, 2002), but within the framework of capital and with wage labour as the dominant form of employment, or, in Marx's term, the dominant relation of production.

Further, while knowledge via the creation and application of technology, does provide the motive force for the techno-economic age, it should not be presumed that we can just read off the actually existing relations or production and distribution from the critical knowledge or core technologies. Within a broad framework of relations of production and distribution the historical development or balance of class and social forces would result in variations within that framework. For instance, it is clear that there are many variants of capitalism, with different forms of private or state ownership of capital and forms of wage labour along with non-wage forms of income distribution, as discussed in Charles Bettelheim's *Class Struggles in the USSR* (Bettelheim, 1976) and in *Varieties of Capitalism* (Hall and Soskice, 2001).

We now turn to see how the above analytical framework of knowledge driving history through technology and related relations of production and distribution can be used to

look at some turning points in human history – those of the Stone Age in Africa, with the control of fire, and the creation of tools and language; the Iron Age in Ancient India; the European Industrial Revolution with the mechanization of manual labour; and the current Age of AI (Artificial Intelligence) with the potential automation of both manual and much of intellectual labour.

The Singularity in Africa

The first two areas of scientific knowledge in creating technologies are making tools and controlling fire. Obviously, we must infer knowledge from remains of their activities and tools. For instance, from gathering and hunting, we can infer that successful humans learned the right seasons for hunting different species of game or gathering various types of eggs, fruits, and other plant materials. “To do so successfully he must eventually decipher the calendar of the heavens: he must observe the phases of the moon and the risings of stars and compare these observations with the botanical and zoological ones already mentioned,” (Childe, 1936: 51).

With tools, whether organic or stone, people would have knowledge of materials and their properties. Further, tools involve techniques of manufacture. Only after humans had acquired these manufacturing capabilities could tools be successfully made for different purposes.

In discussions of tool making, the focus is usually on sharp-edged stone tools, as part of the Man the Hunter tradition in anthropology and archaeology. Were there organic tools, such as carrying bags, pointed sticks, or early spears? Organic materials do not do well in the archaeological record. But “Ethological information indicates that across the Primate order, organic tool use is much more abundant (e.g. leaves, twigs, branches, etc.) Such tool use is seen in all great apes,” (Luncz et al, 2022: 4). This makes it likely that organic tool use was important in the period of evolution of the *Homo* lineage. Carrier bags and wooden digging sticks or spears could have been the first tools of *Homo erectus,* and “Pounding tools have recently received an increase in research interest as they have been suggested to predate the creation of such sharp-edged tools” (Luncz et al, 2022: 20).

If we accept the “woman the gatherer” thesis (Dahlberg, 1983) then it would follow that women were the first to fashion the organic tools which comprised an invisible “organic tool age” (Nedner et al, 2020 and Hurcombe, 2014). But because much evidence, even in studies of contemporary hunter-gatherer societies, shows that women took part in purposive hunting (Kelkar and Nathan, 2002), men likely also took part in gathering, at least until hunting big game became a major part of food procurement. At some point, there was a less strict division of labour between gathering and hunting, as shown by

graves of women and men in pre-Hellenic or Old Europe with identical tools as grave goods (Gimbutas, 1991).

The second technological innovation was controlling fire. Controlled fire not only provided warmth and security (as other animals feared fire) but, most importantly, allowed humans to ingest and digest more calories. The anthropologist Wrangham (1999) argued that fire, because cooking enabled higher nutrient intake, was instrumental in brain growth, resulting in a brain-to-body ratio twice that of other apes, which may be the point at which humans differed from the Great Apes.

Controlling fire involved science: observing and comparing experiences (Childe, 1936: 50). It allowed humans to go beyond other animals by controlling a major physical force and chemically changing the food they consumed. The hunter-gatherers of the Andaman Islands told Radcliffe-Brown that fire distinguished them from animals (Radcliffe-Brown, 1923).

The next creation (technology?) was that of language.[3] Communication exists between animals and even organisms, such as trees (Wohlleben, 2016). But human language has a complexity that other beings do not have. Other animals also have imperative labels, such as dogs that know what yields a treat or monkeys that convey what kind of danger there is, terrestrial or from the sky. But humans also have arbitrary declarative labels that assign an object an arbitrary symbol and grammar too. Further, Great Apes have at most one hundred sounds and gestures, no animal has a language of human complexity.

Language, a human creation, enabled humans to transfer a range of inner thoughts and to learn from each other – not just by imitating what they see, which other animals also do, but by conveying their imagined actions, all the way from tool making, hunting, gathering, to the coordination of foraging and hunting (Bennett, 2021: 302).

Most importantly, language allowed knowledge to accumulate across generations. Not only did brains get bigger, but people also developed many specialised activities, such as spear or stone tool making, cloth making, and so on. With the larger food intake, populations also grew, increasing the number of persons who could share and accumulate knowledge. Later, in the Bronze Age, writing allowed knowledge to accumulate across generations and become accessible beyond what individuals or groups could remember.

To summarize the growth of knowledge: from identification of the useful qualities of plant and animal foods to relating their availability to changes in seasons and times, from controlling to knowing how to make fire, from knowledge of the properties of materials such as organic substances and stones, from making pounding to sharp-edged tools, and

[3] This portion is based on Max Bennett (2023).

language. These main areas of knowledge led to the innovations of our Homo lineage that created the Stone Age, beginning in the savannah of the East African Rift Valley. All of these, particularly the accumulation of knowledge through language, created a positive feedback loop - from larger brains to more accumulated knowledge that led to a marked change in humans' productivity, reflected in a sharp or non-linear increase in human population and their spread across much of the world.

The growth of knowledge, its embodiment in technology and production systems, was also accompanied by a change in relations of production and reproduction. Cooperative activity occurs widely in the animal world, but cooperation among unrelated individuals is unique to humans (Anton and Snodgrass, 2012). Rock art in many parts of the world shows a similar pattern of men's cooperative activities in hunting and war (Bowles and Gintis, 2011).

Cooperation would have increased societies' ability to hunt and process food. Cooperation, as in hunting large animals, had a possible add-on effect – sharing. The meat of large animals was too much to be consumed by one family and, to avoid wasting, had to be shared among the numerous family groups that constituted a gatherer-hunter band.

There, however, is another form of cooperation that has not received the attention it deserves in evolutionary analysis, probably because it privileges the sphere of production over that of reproduction. This is what is called cooperative breeding, which includes not only mothers but also others, analyzed in Sarah Hrdy's *Mothers and Others: The Evolutionary Origins of Mutual Understanding* (Hrdy 2009). "Cooperative breeding would have contributed to the ability of hominins to support the growth and high maintenance costs of large brains among juveniles through care and provisioning and would also have selected for enhanced social cognitive processes that may have led to further increases in brain size," (Anton and Snodgrass, 2012: S489).

Cooperation and sharing thus developed as relations of production and reproduction. This, however, was not the only development; human knowledge also led to foraging with organic and stone tools, and cooking. There was also struggle over resources, warfare and even the formation of a gender division of labour, with cooking becoming a female activity (Wrangham et al, 1999: 575). In one way or another, as Jack Goody points out, cooking is a female activity in most societies. This establishes a gender division of labour that is a way of organizing social labour and developing different capabilities. Thus, we see forms of cooperation, sharing, a gender division of labour and warfare accompanying the knowledge-based development of tools and cooking.

Iron Age in India

If language is critical to communicating and accumulating knowledge, mathematics is critical to calculations important in various forms of production. Ancient Indian mathematical creations, such as zero and the decimal place system, were transmitted across the world not along the land-based Silk Road but, as William Dalrymple (2024) argues, across the sea-based Golden Road to West Asia, across North Africa, and to Europe. Mathematical ideas circulated between India and Greece (Mumford, 2010). The Greek zodiac of 12 solar constellations became part of Indian astronomy. At the same time, well before Pythagoras, Indians knew the right-angled theorem formulated by Baudhayana (roughly 800BCE). There may well have been simultaneous discovery of relations and processes in different civilizations, besides transmission through communication.

We briefly take up three areas of knowledge that developed in Ancient India – mathematics, the related astronomy and medicine and their relation to production.

The zero and the decimal-place system became the basis of merchants' ledgers and accounts. Debts were included as negative numbers. The "Fibonacci sequence known as the foundation of modern banking, formulated in 15th-century Italy, appears in 500-800BCE in the work of Virahamka (Mumford, 2010). Geometry, such as that of the right-angled triangle, was central to the layout of temples and fireplaces. It was also used in the layout of reservoirs and irrigation. Astronomy, the observation of stars and planets and their relation to seasons, was used to forecast the times of planting, irrigation and harvesting.

The systematization and theorization of observation and experiences was important in the formation of the Ayurvedic medical system (Chattopadhyaya, 1977). Both Carvaka and Susruta, authorities of Ayurvedic medicine, rejected divine intervention, karma, or demonic possession in understanding health problems. They held that the body was made of matter and interacted with the environment (Chattopadhaya, 1977). British doctors in India in the 18th century were surprised to note the well-developed system of rhinoplasty, reconstructive surgery for nose-cutting meted out as a form of punishment (Govindnathan, 2027).

The Manusmriti highlights the social valuation of knowledge, or the respect due to it.[4] In ascending order, "Wealth, kinship, age, actions, and fifth, learning are the basis for respect" (Doniger and Smith, 1991: 2, 136). Learning is the acquisition of knowledge; so, learning as the basis for respect really means knowledge as the basis of respect. The status accorded to knowledge as a basis of respect is similar to the modern concept of knowledge as a meta resource, since it enables the use of all other resources and creates wealth (Nathan, 2024).

[4] This section is based on Nathan, Kelkar and Govindnathan (2022).

In Ancient India, however, not all knowledge was accorded the same status. In Early Ancient India, healers were of high status, but with the rigidification of the caste system they came to be regarded as a low occupation as they dealt with bodily fluids and corpses. In *Manusmriti*, which can be regarded as the definitive text of the rigid caste system, healers were described as of a "lowly and reprehensible occupation" (10.46 in Doniger and Smith, 1991). In verse 4.220, the food given by the physician is denounced as being "pus". Other verses of *Manusmriti* – 3.152, 3.180, 4.212, and 4.220 also describe the low status of physicians; which must also mean of their knowledge.

Knowledge of the Vedas was accorded the highest respect, since the Brahmin, the one who acquired knowledge of the Vedas, "was born of the highest part of the body [the mouth]" (Manu 1, 93). The next level of respect was accorded to the Kshatriya (warrior) and the Vaisya (trader and artisan), while the Sudra, the service castes, were the lowest and most despised. The untouchables, who initially were referred to as outcastes, were the fifth caste, now referred to as Dalits or the downtrodden. They carried out the essential tasks of cleaning and scavenging.

The ontology of the caste system is that of a hierarchy of statuses of humans, where the essence of each caste is held to be different. This is somewhat similar to the Confucian ontology, where too all humans do not have a common essence (Descola, 2013). The hierarchy of essences also leads to a hierarchy of the knowledge that each caste and gender possesses.

In the ancient Hindu division of labour, the one social sphere reserved for women was social reproduction. Women's knowledge of household labour and management, however, was not counted as knowledge. They seem to be of the same order of nature as women's nurturing role. Further, the woman's role as mother is devalued by the notion of the second birth of male initiation, which was held to be more important. The second birth of male initiation meant that after physical birth, men were culturally reborn and introduced into the masculine order (Roy 1999: 94). A mother is a nurturer, but she is not given the status of a knowledge possessor. Woman as mother might be extolled in various texts, but her knowledge is devalued (Nathan, Kelkar and Govindnathan, 2023). Women, as mid-wives, become part of the untouchable castes.

The Industrial Revolution

The Industrial Revolution is the next major economic development we deal with. This, of course, is what Marx referred to in his statement in *The Poverty of Philosophy* (1847), where he wrote: *"*The hand-mill gives you society with the feudal lord; the steam-mill, society with the industrial capitalist.*"* First, however, society or Britain, in this case, needs to develop the steam-mill or factory production.

The use of steam power to run a set of machines (looms or spinning jennies) went beyond the tinkering development of the spinning jenny. Spinning jennies could be made with just the prescriptive knowledge of the what and the how to make a jenny, without the propositional knowledge of the why. But setting up factories where jennies were connected to steam power did require knowledge of the mechanical sciences (Jacob, 2014).

The conceptual breakthough in the steam engine was in transforming heat into mechanical work (Mokyr, 1992). Further, practitioners and scientists interacted, with each side feeding the other in a feedback loop (Mokyr, 2002). These technological developments resulted from combining skilled hands (the tinkerers) with scientists in the new mechanical sciences. Engineers and skilled workers often attended lectures by university scientists, and they combined in working on the issues of turning scientific knowledge into technology (Jacob, 2014).

Feedback loops, based on communication between analysts or theorists and artisans or workers, were important in the development of science into technology in Europe. Weaker social distinctions tend to allow the interaction and integration of disparate components of knowledge, which, according to Renn (2020: 215), was characteristic of science and technology in Western Europe in the early modern period. “It is the strong complementarity, the continued feedback between the two systems of knowledge [propositional and prescriptive] that set the new course,” (Mokyr, 2002: 65).

The new course led to the mechanization of one industry after another. This increased productivity and GDP growth. With the technology reasonably protected by intellectual property rights and more so, the doctrine of comparative advantage that supported specialization of one part of the world in high-return manufacturing and another part of the world in low-return agriculture and raw materials production, it led to the Great Divergence in per capita incomes between these two parts of the world.

The new scientific knowledge-based technology, however, also transformed relations of production, which is what Marx’s statement refers to: “…, the steam-mill society with the industrial capitalist.” The establishment of the factory method of production required the social creation of two classes. One was the capitalist, who initially accumulated capital primarily through trade, money-lending, and other means, such as slave-trading and plunder. This money could be turned into capital invested in a factory. The factory also required a class of workers, of those who did not own the means of production (unlike the artisan) and would, therefore, be willing to sell their labour-power for a wage, i.e. become a class of wage labourers.

These changes did not come about on their own. The classes of capitalists and wage labourers emerged through class struggle. The nascent bourgeoisie fought to reduce the political role of the landlords and gentry and eliminate them economically. The latter did

so by abolishing the Corn Laws, which used to protect British agriculture from cheaper foreign competition and kept corn prices high, which in turn kept wages high. The enclosure of the commons promoted the formation of a class of propertyless labourers who had nothing to sell but their labour power for wages (Thompson, 1991). This enclosure, by cutting off small peasants from petty agriculture on common lands, forced them to migrate to urban centres as the new working class. The remnants of commons in traditional transactions were ended through violence, including that of witch hunts (Kelkar and Nathan, 2020). And the anti-mechanisation Luddites were defeated in their efforts to stop the replacement of artisanal workshops with factories.

Thus, we have a sequence establishing a new society, even a new world order: scientific knowledge, particularly of the mechanical sciences; the setting up of factories that combined steam energy (later electricity) with machines; in a society with two major classes of capitalists and wage labourers; these classes being formed or establishing their political and economic supremacy in the case of the industrialists through political struggles; overall, producing an unprecedented, sustained increase in productivity and per capita income; along with the division of the world into manufacturing and agriculturist-cum-raw material producing countries with a Great Divergence in per capita incomes.

The key factor in the above transformation is that of the mechanization of manual labour.

Asian Stagnation in Knowledge Creation and Technology Use

Francis Bacon in 1692 said that three discoveries – printing, gunpowder and the magnetic compass - were unknown to the ancients (meaning Ancient Greeks) and their "origin is obscure and inglorious" (quoted in Needham, 1987: xxx). It was Needham who, with his colleagues working on *Science and Civilization in China*, showed that these discoveries originated in China well before they were known to Europe. Gunpowder was first referred to in a Daoist text warning not to mix saltpetre (potassium nitrate, sulphur and carbon) as it would make an explosive substance (Needham, 1987: 1), and that gunpowder was put in simple bombs and grenades around 1,000CE. The discovery of gunpowder was a matter of serendipity, much as the discovery of penicillin many centuries later.

Paper was invented in China well before the Common Era, woodblock printing around 700CE and movable type around 1100 (Needham, 1985). Finally, the magnetic compass was invented during the Han dynasty (202BCE to 220CE) and was initially known as "South Pointing Fish" (Needham, 1963). A later iron needle compass allowed Admiral Zheng He to lead a fleet of 317 ships and some 27,000 men to sail right up to India (the Malabar Cost) and Africa (https://daily.jstor.org/zheng-he-the-great-eunuch-admiral/) around 1400.

Needham pointed out that these inventions either originated or were radically transformed during the Song dynasty (960 to 1279 CE), at which time China was far in advance of Europe in science and technology. As he himself asked the famous counterfactual question, "Why did the Scientific Revolution not take place in China (or India)?" (1969).

Following Kuhn (1962), we can say there have been and will be many scientific revolutions and in each of them a prevailing scientific (or knowledge) paradigm is replaced by another one. At some point observations contradict established theory, requiring its replacement by a new theory that is able to account for what would be anomalies. Such a forward movement requires, first of all, that there not be an established authority that does not allow rejection or replacement of theories. In Europe there was the struggle over the Copernican theory replacing the older Ptolemaic theory, or the theory of the circulation of blood developed by Harvey which replaced the Greek medical system of Gallen (Goldstone, 2006:9).

In contrast, we should note the opposition to new theories in China and India. From 1644 onward, the Manchus of China: "in order to demonstrate their right to tule, decided to propagate a 'pure' form of Confucianism .... All opinions outside of Confucianism were banned. Although there was progress in practical areas of agriculture and managing irrigation and flood works, scientific progress and innovation were virtually halted," (Goldstone, 2006: 9).

In India, Debiprosad Chattopadhyaya (1977) argued that from the Gupta Empire in the early centuries of the Common Era, religious orthodoxy inhibited the changing of theories of Ayurveda, despite the accumulation of evidence that went against the foundational theories of Ayurveda. A Dutch scholar of Indian medicine pointed out, "... it is also one of the basic characteristics of ayurveda that despite this acumen [in observation], the anomalies observed did not become an incentive for the improvement of the theory or the formulation of supplementary rules. The reason for this stagnation of creative thought may have been the increasing domination of orthodox religion and the power of its representatives" (Meulenbeld, 1987: 4).

Stagnation in Asian knowledge systems resulted from politically imposed requirements to confirm to religious or state doctrines. This should serve as a warning to glib evaluations of knowledge catch-up and technological go-ahead policies in Asian and other countries.

The example of Ayurveda given above points to one more factor in Asia's falling behind in scientific development – the lack of connections between different circuits of knowledge which inhibits the multi-level network connections that build feedback loops that provide increasing returns in the development of knowledge. As discussed in reference to the Industrial Revolution in Europe, there were close connections between theorists and

scientists with engineers and skilled workers which spurred sustained increases in knowledge.

There is another analysis of the reasons for Asia falling behind Europe in scientific development. Justin Lin (1996) who argued that there was a methodological difference between Asian and European knowledge systems in the Scientific Revolution. The former were based on observation and experience; while the latter were based on formalized scientific experiments. In the former system large populations with many more observations, provided a larger base for the advance of knowledge. On the other hand, the system of scientific experiments required more trained persons, and not a larger population.

We should end with one more analysis of the Europe-Asia divergence. Needham himself puts forward the Marxist analysis that the growth of capitalism in Europe led to a demand for more and more science, as capitalists sought to gain an advantage over competitors; while China around the same time, was more bureaucratically organized, without incentives to increase productivity or make new products. Even the use of existing technology, such as printing, was constrained by cultural factors. Printing was invented in China and known, for instance, in Mughal India but the failure to adopt printing has been ascribed to a desire to protect the profession of scribes, or to cultural resistance (Richards, 1996. It was the Reformation in Europe with its doctrine that every person could directly communicate with God, that led to the printing of millions of copies of the Bible between 1450 and 1600..

This Asian falling behind in both the creation and use of knowledge, including military knowledge, played a key role in the European conquest and colonization of much of the rest of the world.

Military Knowledge and European Colonialism

The European conquest and colonization of much of the rest of the world is a period of world historic significance. It was brought about by and perpetuated violence on a scale not seen before. It set up the slave trade, connecting Africa, the Americas and Europe. It brought the world together, though in a very unequal manner. What was the role of knowledge in this part of world history? [5]

The Industrial Revolution led to factory-made rifles and the machine gun. This, along with the industrial organisation of military units, gave European nations a superior military force that could conquer the world. However, European colonialism predated the

[5] This section is a reply to Gerry Rodgers who, in an email, asked me, “So, has knowledge replaced gunboat diplomacy?” to which I had responded that knowledge was the basis of gunboat diplomacy.

Industrial Revolution. Nevertheless, European military superiority in the pre-Industrial Revolution period was also labelled the military revolution (Parker, 1996).

One factor identified in Asian defeat was that the Asian empires (India and China) were primarily land-based and thus did not see the need to develop as naval powers. By contrast, naval competition among the coastal nations of Western Europe led them to develop naval warfare methods superior to those of the Asian empires (Black, 2015). The European armies developed what might be called a forerunner of the Taylorist method of organization, with units organized under single command. They also developed armies of paid soldiers rather than levies commanded by feudal lords of dubious loyalty. All in all, the European militaries embodied superior knowledge both in armaments technology and the organisation of armed forces.

After defeat in the Opium Wars of the mid-19th century, the "Self-strengthening Movement" in China argued that China's defeat stemmed from the military technology gap between China and the West (Kroeber 2024). More recently, an Indian scholar has also identified superior European military technology as the reason India was conquered by European powers (Kumar, 2025). It was the superior military knowledge of the European powers- knowledge not only in military technology but also in the organisation of the military, in a manner of the techno-military paradigm of capitalism- that powered Europe's conquest of much of the world.

We now turn to the development of Artificial Intelligence (AI) and its implications for the economic organization of society.

Artificial Intelligence (AI)

Following Arthur (2009) radically novel technologies are based on the application of some new natural principle. It is based on the theory of neural networks, networks on which brains function. AI is concerned not just with understanding but also with building intelligent machines, i.e., "machines that can compute how to act effectively and safely in a wide variety of situations" (Russell and Norvig, 2022: 21).

The core of AI is machine learning, which itself has gone through many transformations, with the most important being that from "hand-crafted knowledge to machine-learning from data" (Russell and Norvig 2020: 52). It is certainly a general-purpose technology affecting not just all areas of production but even any intellectual task.

Before AI, machines could take over manual work, as was the basis of the Industrial Revolution. With IT, computerised algorithms could also take over routine cognitive work (Acemoglu, Autor, and Johnson, 2026), as seen in algorithms used in the production of both goods and services.

The first example of a machine that undertakes routine cognitive work in production is the Jacquard weaving loom, created in 1804, in which weaving instructions, or weaving software, were embedded in punched cards, much as punched cards were used in early computers. The Jacquard loom, however, could only follow the instructions in the punched cards. Now, with AI, machines can learn and correct errors, embodying Arrow's learning by doing. This allows them into the realm of acquiring the tacit knowledge of non-routine cognitive work that Acemoglu, Autor, and Robinson (2026) hope would remain the unique domain of humans.

In brief, the critical knowledge behind Artificial Intelligence is studying and mimicking neural networks and learning in human brains. From machines in the Industrial Revolution that could be set to perform certain actions, we now have machines that can carry out unsupervised learning.

AI is a general-purpose technology that can be used in virtually every human activity, whether in office work or factory production, or in education, healthcare, and movie-making. AI, as software, can automate many office functions and prepare material for informed decision-making by human personnel. AI can be combined with robots to create automated production systems that can learn and make corrections. This has led to the establishment of dark factories, i.e., factories with no humans on the production line and thus not requiring lights. There are many dark factories in China, and even one in India.

What is the techno-economic paradigm that will be associated with the Age of AI?

AI-Robots and Labour

Autor. Levy and Murnane (2003)_made an important distinction between routine and non-routine cognitive functions. The former are mental actions that are repeated and based on algorithmic calculations, such as administration and accounting, and can then be automated by algorithm-based AI agents. On the other hand, functions such as business decision-making, which use tacit knowledge, are non-routine and cannot be reduced to algorithms for AI agents to carry out. However, AI development is based on identifying patterns and learning through iteration. Through learning by doing, AI can undertake some non-routine functions which involve different types of discretionary decisions. Both Anthropic and OpenAI report that AI carries out many non-routine functions; but because it learns, it may not be able to act or decide based on emotional or other psychological factors. But for, say, discretionary business decisions, there seems to be no reason to hold that AI cannot learn them. The Autor, Levy, Murnane distinction then ceases to be a barrier to using AI.

In a subsequent paper, Acemoglu, Autor and Johnson (2026) argue for an AI future that augments, rather than automates, work. But augmentation will increase the productivity of the augmented workers and, thus, require fewer augmented workers for the same

amount of output. Teams will become smaller and be able to take on more tasks, including those carried out by humans and those automated by AI, within given time periods. By distinguishing between routine and non-routine cognitive functions, senior researchers, for instance, will be able to work without human RAs. In either case, employment in the research function will decline as senior researchers work with AI agents rather than human RAs. The workforce required to carry out any quantity of work will necessarily shrink. Further, as Chopra et al (2026) calculated, the direct reduction in jobs, as seen in the example above, is only the tip of the iceberg. Their study of banking and finance shows concomitant reductions in employment in areas like human resources, finance, and accounts, as fewer technical employees mean fewer requirements for employees in these supplementary functions. They estimate that the full iceberg of AI-induced unemployment is more than the visible direct employment loss. Augmentation also leads to job loss, though not as directly as automation.

Automation is likely to take hold first in tasks involving more routine work. Since more routine work is located in low- and middle-income countries (Lewandowski and Szymzck 2020), or the Global South, these countries will be affected as industries or tasks could relocate to the Global North. This relocation will also affect the outsourced supply of business services, such as IT software services, on which India has built its current development model. As corporations seek to maintain control over AI-enabled systems critical to their functioning, Indian companies currently engaged in outsourced office work would lose much of their current work. The restructured offshore centres, however, could become the new Global Capability Centres (GCCs) that Forbes 2,000 companies are setting up in India. But these GCCs would also be subject to AI-driven automation, with fewer employees per unit of service. Employment in offshore office work will fall.

The Global South with a higher proportion of routine task-based employment, whether in offices or factories, will be substantially affected by AI-based automation of office and factory work. With dark factories, there could even be a relocation of currently labour-intensive manufacturing to the Global North; of course, without creating much employment there too.

Depending on the extent and speed of automation, there will be substantial unemployment even in the Global North. This will affect not only those working in largely routine manual and cognitive tasks, but also those in somewhat non-routine cognitive tasks, as fewer of them will be required. For instance, an important part of education is one-to-one tutoring. As AI agents take over such tutoring, it would become almost costless, as is the case with online streaming. Large-scale displacement of labour, growing over time, is an inevitable effect of AI-Robotic automation.

Left to the tech giants (both US and Chinese) that own AI, and the continued development of learning machines, we will see an age of AI with competing empires of AI, backed by

their respective states. But this will be a very unstable world order, not only because of the competition between tech giants and their states, but also because of the macroeconomics of AI, which we go into below.

Will This Time Be Different?

This is not the first time there has been labour-displacing mechanization, if not automation. But the jobs lost in earlier mechanization and automation have been covered by two related developments. First, new industries have created jobs. When horses were replaced by automobiles, new jobs emerged not only in automobile manufacture but also in supplementary occupations such as drivers and petrol station attendants. Second, the increase in per capita income brought about by higher productivity led to increased demand for other services and facilities, such as schools, recreation, suburban homes, etc. Further, higher productivity also raised wages, such as the living wage pioneered on a large scale at the Ford motor factory, which allowed consumption growth to match mass production. This was the creative part of Schumpeter's creative destruction; the destruction was the demise of horse-drawn transport.

The current scenario differs in some ways. First, the displaced workers performing routine tasks, whether manual or cognitive, will be replaced by those with higher education and skills performing non-routine work. But per unit of output, the new jobs will require far fewer workers than the old jobs. This will increase inequality among the workers who remain in some form of employment. Along with this, the AI-robotized production system is highly capital-intensive, and profit share will increase, raising inequality. This inequality will also increase between the Global North and the Global South, because, as mentioned above, the latter has a higher proportion of routine-task jobs than the former. In addition, the US and China dominate ownership of basic AI technology. The growing inequality with lower wage share will lead to a reduction, even collapse of demand, particularly for basics, which would include not only houses but even automobiles in the Global North.

During the Industrial Revolution, the wage share fell during what was known as the Engels' Pause. But this shortfall in domestic consumption was made up for by export markets in the then-colonial countries (Luxemburg, 1968; Pattnaik, 2001; Nathan, 2024). This time the Global South will itself also be affected by the fall in wage share and demand.

Discussions on the impact of AI usually mention unemployment, but neglect the macro-economic demand effect of unemployment. The resulting global shortfall in demand is not something Keynesian deficit financing could meet, because it is not a temporary fall in total demand. Rather, it results from a change in the distribution of income: a decrease in the wage share and an increase in the profit share. Branko Milanovic (2026) also argues that the AI-based economy will face the problem of structurally inadequate effective demand. It will either reform or collapse.

It is logically possible for the change in income shares to be met with a change in the composition of production, a move away from basics to conspicuous consumption, such as luxury yachts and space tourism, along with the necessary high consumption out of profits. The combination of high luxury consumption and investment by the tech giants could, logically, forestall a collapse of effective demand. But the continuing of such an enormously unequal distribution of income would have its own socio-political consequences and would certainly lead to revolts of varying intensities against the 0.0001% or even less of the population.

Beyond Wage Labour

To deal with this problem of the collapse of consumer demand ("Who will buy your cars?" a trade union leader is reported to have asked Ford, when threatened with robotized production at some time) some, including Geoffrey Hinton, Nobel Prize winner for his work on AI, have proposed a universal basic income (UBI), or a variant in the form of universal basic services (UBS).

A UBI, however, would signal a change in the economic system or the techno-economic paradigm. The UBI proposals show that the new economic system based on AI-robotization can no longer function with the older capitalist norm of income or wages tied to being a wage employee. Not being a wage employee meant being unemployed, or without an income. It was in dealing with both the demand deficit and the political consequences of unemployment, resulting in zero consumption or death, that unemployment compensation was initiated as a measure of social protection. In a sense, this marks the beginning of moving away from the capitalist system in which workers' income is tied to employment. The UBI system carries this to its logical conclusion: when human employment is not needed, or is barely needed, to carry on production, the only way humans would not go the way of horses is for human income not to be linked to employment. Leontief asked whether, with technological advancement, humans would go the way of horses. They would, if income and consumption were not delinked from employment. Only a few humans would be left to serve the 0.00001% "tech giants," and not many more would have wage employment. This would be a system of capital without wage employees – but with high levels of taxes on capital to make a UBI possible.

There are some other possible alternatives. In a provocative piece, Richard Freeman (2015) asked: what if workers owned the robots? Nathan and Kelkar (1998), based on their study of collective villages in the Chinese market, discuss a system of village /worker ownership of enterprises in a market system. This would mean workers would own the enterprises and, thus, acquire the income that would otherwise go to capital. There could also be state ownership of capital, with the UBI being paid out as a share of profits to all citizens. Bardhan and Roemer (1993) discuss an enterprise-based market system in

which the public owns the enterprise through shares in mutual funds. The income from these mutual funds would be distributed among citizens. This develops the idea of income from sovereign wealth funds accruing to citizens. Another alternative is the Mondragon Cooperatives in the Basque Country of Spain, which are also a form of worker ownership.

Politically establishing these forms of what have been called market socialism (Bardhan and Roemer 1993) would have to overcome the power of the tech corporations whose owners will form the Age of Trillionaires. The balance of political forces and self-conscious citizens (former workers?) will determine which outcome prevails. That, too, would require changing intellectual property rights so as not to create intellectual monopoly capital. Even state-owned or nation-owned corporations or cooperatives could be expansionist and compete technologically to rule the world. This could stop if the intellectual property rights system were simultaneously designed to prevent intellectual monopoly capital.

The development of human knowledge to the point where we can make learning machines, which might even make themselves, creates possibilities for new techno-economic paradigms – a world of competing empires of AI, with their corresponding states, very high global and within country inequality, matched by high luxury consumption and high rates of investment out of profits, along with 'bread and circuses' for the vast majority; a world of collectively moderated empires of AI with Universal Basic Income; and a world of collectively-owned AI with citizens securing shares of AI income. Which possibility comes about (could there be an alternative beyond these three?) will depend on the balance of political forces between AI corporations and their states and the rest of the world; and between AI corporations and citizens within countries. Class struggle will determine which possible world we move into, if we have not destroyed planet Earth or humanity before then.

Conclusion

In this essay, I have tried to develop an analysis of what Marx called 'the *active* side' (1845, emphasis in the original), which he said materialism had ignored. This active side is identified as the creation of knowledge, its transformation into and interaction with technology, and the subsequent creation of techno-economic paradigms. This note shows how this process worked out in some critical transformations in history: the Stone Age, the Iron Age in India, the Industrial Revolution, and the nascent Age of AI. This analysis can also be applied to other major historical transformations.

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