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Cosmographies for the Discovery, Development and Diffusion of Useful and Reliable Knowledge in Pre-Industrial Europe and Late Imperial China: A Survey and Speculation

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Cosmographies for the Discovery, Development and Diffusion of Useful and Reliable Knowledge in Pre-Industrial Europe and Late Imperial China: A Survey and Speculation

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> "I meditated upon this lack of certitude in traditional mathematics concerning movements in the spheres of the world and began to be annoyed that philosophers had discovered no sure scheme from the movement of the marching of the world which had been built for us by the Best and Most Orderly Workman of all". (*Copernicus 1543)*[*]

The inspiration for this bibliographic survey comes from the recent announcement that this years' Nobel Prize in economics has been awarded to Nordhaus and Romer for their contributions towards "integrating nature and knowledge into economics". Economic historians have been engaged with those two programmes for some time, and the location for this working paper resides in metanarratives celebrating the economic rise of the west that have been challenged in recent in recent times by two theses formulated and defended by the California and World Systems Schools of historical sociology (Daly, 2015). The first continues to insist that economic divergence between the Occident and Orient became apparent much later than generations of Eurocentric historians have suggested. It reconfigures the economic history of pre-modern centuries into a world of 'surprising resemblances' (Pomeranz, 2000). It also rejects assertions that Europe alone had developed the states, cultures and institutions for an early and sustained transition to modern economic growth (Wong, 1997). While the second explains more than three centuries of divergence between east and west, with reference to

[*] Quoted by S. Nakayama, Academic Scientific Traditions in China, Japan and the West (Tokyo, Tokyo University, 1984) p.24

Europe's favourable location and natural endowments, combined with high and persistent levels of investment in warfare, colonization and mercantilist policies that (by way of coercion and unequal exchange) enabled Europeans to garner most of the gains from trade that flowed from proto-globalization over the centuries between 1415 and 1846 (Wallerstein, 1974, 1980, 1989 and 2011 and Frank, 1998).

Counter attacks by European and American historians have concentrated upon the collection, calibration and comparison of statistical evidence deemed to demonstrate that divergence could be located in time and explained (as Weberians have long maintained) with reference to traditional and deep-seated structural, cultural and institutional contrasts between Occident and Orient (Maddison, 2007 and Broadberry et al., 2011).

Unfortunately and due largely to the quality and paucity of statistics available for China and India, scholarly endeavours to substantiate that Eurocentred view by measuring GDP per capita in international dollars and estimating nominal daily wage rates in grams of silver, calorific equivalents, or constant prices have been exposed as conceptually and statistically flawed exercises in quantification (Broadberry et al., 2006, Deng and O'Brien, 2015). Pomeranz has, moreover, long advocated that reciprocal comparisons are realistically confined to economic regions that are not too different or too far apart in scale or potential for development. Following his advice and utilizing the tiny samples of imperfect data published by Bozhong Li, Deng and O'Brien, have compared kilocalories of nutrients from rice available to modal peasant families in the Yangtze Delta with calibrated figures for kilocalories from wheat and oats accessible to families of the labouring poor in England for just 5 'benchmarked' years between 1650 and 1850. They have published for debate and negotiation a contestable base of evidence that suggests that over these centuries ostensibly comparable families in England may have enjoyed higher and rising standards of living compared to their counterparts living in Jiangnan (Deng and O'Brien, 2015).

As they read the history of that economically advanced province of the Qing Empire, they observed a peasantry engaged in a *kauf* system of production, cultivating grains and processing organic fibres into coarse ramie and cotton cloth for sale on local, regional and imperial markets (Kuroda, 2018). By the late seventeenth century when Malthusian pressures emerged in China the reallocation of family labour seems to have been supplemented by fixed rents, low taxes, longer working hours; but not (compared with England) by migration to towns in the Delta or to mass migration to distant frontiers within the empire let alone to potentially colonized rice bowl territories in South East Asia (Vries, 2015). When deterioration in the net barter and factoral terms of trade between cloth and grains intensified, pressures from rapid population growth were compounded by the failures of a physiocratic (but under-funded) state to tax and invest in China's depreciating infra-structure for agrarian production (Elvin, 2004).

Meanwhile, over these same centuries, England's aggressive and well-funded mercantilist policies actively promoted its protracted transition to an industrial market economy (O'Brien, 2014). And it has now been established that the land, foodstuffs, minerals, timber and energy utilized to support initial stages of that precocious transition did not emanate in any significant degree from American colonies, but came from within the kingdom (Wrigley, 2016, Otojanov 2018). Furthermore, China's expanding Qing Empire also included under-exploited cultivable ghost acres and accessible reserves of coal (Fouquet, 2008).

England's accelerated industrialization and urbanization are now being represented as the outcomes of long historical cycles that witnessed its agriculture's early escape from the Malthusian trap, followed in time by a marked rise in total factor productivity, sustained by gains from foreign trade (Allen, 2009 and Broadberry et al., 2015). Thus, a core chapter of narratives accounting for the Great Divergence should logically be devoted to an analysis and comparison of regimes (clusters of connected elites, artisans and institutions) engaged with the discovery, development, diffusion and application of innovations based upon useful and reliable knowledge that augmented the productivity of labour employed by

households, farms and firms producing both agricultural and industrial commodities (Mokyr, 2002 and O'Brien, 2009).

Thus, and after some eighteen years of heuristic debate on the Great Divergence, most participants might now agree to: utilize comparative methods that are reciprocal and confined spatially to the economically advanced regional economies of Europe, China, India and the Ottoman empire; to modify Eurocentred concepts and vocabularies; and to admit that the sources available for Asia are simply not adequate, adaptable or accurate enough to support the construction of statistically based *explicanda* or chronologies for pre-modern divergence (Deng and O'Brien, 2015). Above all, it is important to recognize all Eurasian economies continued to cope with the omnipresent threats from more or less acute Malthusian pressures, at a time when global histories of science and technology suggest that some European cultures became permeated by a cosmography that was promotional for the accumulation of useful and reliable knowledge. Gradually the embrace of new knowledge by educated political and wealthy elites embodied a cultural and a more directly applicable potential for advances in total factor productivities that facilitated the escape of western populations from age-old Malthusian threats into modern economic growth before the populations of Asia (Mokyr, 2017).

This view, familiar to contemporaries, was: enunciated by Max Weber, supported a programme of historical research led by Joseph Needham, elaborated by Mark Elvin, analysed in a series of conference papers by The Achievement Project in the 1990s, cogently synthesized in three books by Joel Mokyr and accepted by Ken Pomeranz during the protracted debate that has followed the publication of his seminal book in 2000 (Weber, 1950, Needham, 1969, Elvin, 1973 and 2010, Gouk, 1995 and Pomeranz, 2011).

Given that this and most other connexions between cultural and economic change are not statistically testable, in order to define, configure and locate the accumulation of such an intangible input as knowledge for debates on economic divergence will require analyses focussed upon the histories of contrasting belief

systems behind and linked to institutions promoting or restraining the development of embryo sciences and prototype technologies across Eurasia. Nothing so ambitious or chronologically open-ended could conceivably be summarized in a short essay. Assuming that the established consensus which suggests that the locus of scientific discovery and technological innovation shifted from east to west by, if not sometime before, 1492 is not at issue, I propose to provide nothing more than a blueprint for an opening chapter of a multi-volume account by comparing Europe's own historical trajectory towards the formation and consolidation of a regime for the sustained generation of useful and reliable knowledge with China. For that purpose I will select, reference and survey a bibliography of recent research in the separated but conjoined histories of science, technology, religion, philosophy and cosmography in order to address the hypothesis posed by Weber, popularized by Butterfield and developed by Needham and their modern followers who have suggested that the histories of observed innovations introduced into western agricultures and industries over the centuries that succeeded the discovery of the Americas were connected in some non-trivial degree to changes in conceptions of the natural world held by Europe's educated, wealthy and political elites. 'Cultural' change (as perceived and documented post hoc) led these elites to lend greater and sustained support to networks of proto-scientists, inventors, artisans and to establish institutions that might conceivably generate and adapt knowledge with potential to become instrumental for private profit, for the geopolitical power of states and eventually for the health, security and material welfare of western societies (Vogel, et al., 2010). This thesis that a gestalt switch in mentality shaped by science came on stream in the seventeenth and eighteenth centuries and led the educated to take an active interest in manufacturing and, to quote Sivin "led artisans with everyone else to begin reasoning abstractedly about facts, procedures, commodities and labour to an unprecedented extent in human history" became the subject of a debate between two great sinologists (Joseph Needham and Nathan Sivin) that has matured into an on-going discourse (Needham, 1969, Fraser, 1986, Sivin, 1995, and Wootton, 2016).

Today's successor to early modern networks are 'regimes' that generate flows of modern science and technologies employing highly skilled workforces, engaged with observations, experiments and mathematical reasoning as practiced by a plethora of specialized experts qualified in a multiplicity of disciplines that are organized and funded in ways designed to be efficient for the comprehension and manipulation of the celestial, terrestrial and biological spheres of our natural world (Nelson, 1993).

No society in prehistoric, ancient or premodern times has ever functioned without some sort of regime for the accumulation, consideration and dissemination of knowledge regarded as potentially useful (Montgomery et al., 2016). The histories of these regimes across space and through time as well as analyses of conjunctures when transitions occurred to potentially more efficient systems are the subject of analytical narratives constructed by scholars who continue (as Needham advised) to take a global view of progression towards a deeper comprehension of nature and the augmentation of mankind's powers to control it for benign as well as malign ends (Allen, 2004).

To facilitate the compression of millennia of history, I set aside the 'dialogue of civilizations' behind very long-run global histories of knowledge accumulation (Bala, 2006) as well as entire eras encompassing paleolithic and neolithic times, the diffusion of sedentary agriculture, riverine and coastal urbanization, the spread of writing and mathematics. The contributions of several classical, oriental and occidental civilizations to ways of comprehending and effectively controlling the basic elements of nature, (earth, air, fire, wood and water) will be bypassed but regarded as foundational for an early modern 'stage' in Eurasian history when preconditions coalesced for further and more rapid advances associated with the religious beliefs, elite cultures and the promotional institutions of Christendom (Barnes, 2000 and Davids, 2013).

Stimulated by debates on the Great Divergence challenges to this ostensibly Weberian view have been mounted on two fronts (Duchesne, 2011). The first,

repeats familiar arguments from traditional controversies between science and religion, namely, that beliefs espoused and enforced by Christian churches were at best neutral and at worst, repressive towards investigations into a natural world, created and ordered by Europe's one and only omnipotent God (Grant, 2004). The second and more recent wave of literature from post-modern histories of science maintains that knowledge discovered, developed and utilized for purposes of production was 'socially constructed' (Golinski, 1998). This means that although proto-science continued to originate from several parts of the world its connexions to the cosmographical and religious beliefs espoused by European and the elites of other continents was probably irrelevant, or at best, of tenuous significance for economic histories that emphasize technological change as central for narratives of economic divergence between the occident and orient (Bagioli, 1998 and Osler, 2000).

After the cultural turn and from the altogether more secular perspective of our times, more recent histories of science combined with religion are, however, inclined to accept a well elaborated and persuasive case that suggests on balance the history of monotheistic Christendom, dominated by faith in a single God, who ultimately controlled everything in his divinely created universe, evolved into a belief that *ceteris paribus* embodied elements recognized as significant for the promotion of a functional cosmography for the comprehension of nature (Hannam, 2009).

Prima facie Europe's theologies (Catholic and Protestant alike) can be read as more hospitable for the accumulation and diffusion of useful and reliable knowledge than the animistic, hermetic, polytheistic, awestruck and unintelligible views of nature purveyed by 'priesthoods' of many other traditional systems of belief that provided almost no warrant or place for systematic investigations into the material world separable from the moral and political concerns of societies over which they exercised ideological power on behalf of rulers (Gillespie, 2008 and Tremlin, 2006).

Before the Reformation, propelled in its formative stages by the Roman Empire, European Christianity had consolidated its role as a hegemonic quasi autonomous, hierarchically organized religion that over time had suppressed all but one system of belief about nature and the operations of the natural world in favour of its own revealed truths for which its clergy held a monopoly of interpretation. Nevertheless, as it evolved over the centuries into a supra-national organization the hierarchy of the Roman church recognized that faith in truths as revealed in the New Testament, the Bible and a limited range of other canonical references would not be sufficient for competition with monotheistic Islam, to combat heresies or to retain its ideological influence over royal and aristocratic power. Thus the papacy and bishops found it expedient to establish, patronize and control institutions based upon Greek and Roman models for the higher education of clerical and secular elites that included classical modes of conducting 'rational' arguments in law, medicine, natural philosophy and even theology (Lindberg, 2007).

Under strictly regulated conditions institutions (approximating to proto-type universities) spread across the cities of medieval Europe and established faculties and curricula for compulsory introductory courses in natural philosophy based upon texts by Aristotle, Plato, Ptolemy, Galen, Hippocrates and other pagan authors, that included a corpus of classical speculations about the operations of the celestial, terrestrial and biological spheres of what the church resolutely insisted was a divinely created and ordered natural world (Bullough, 2004). Apart from the accolades bestowed for preserving and diffusing a heritage of classical beliefs and theories about that world, higher education in natural philosophy developed in ways that has, however, been represented in an entirely negative light by a long and thickening line of medieval and early modern critics who undermined and ultimately overturned both the subject's modes of enquiry and its claims to authoritative and utilitarian understandings of planet earth, the solar system, human health and animal biology (Harrison, 2010).

But and thanks to an impressive programme of research from a school of American scholars into the medieval origins of modern science the denigration of a long tradition of classical and post-classical endeavours to comprehend the natural world as misleading and subservient scholasticism has been more or less degraded (Lindberg, 2007). Historians have become educated on how far and how deeply Europe's cosmographical levels of comprehension had developed before their displacement by a reconfigured cosmography and innovative paradigms for an accelerated accumulation of more useful and reliable knowledge that evolved decade by decade after the publication of a seminal book in astronomy by Copernicus in 1543 which marks the onset of what many historians continue to refer to as the scientific revolution (Grant, 2007).

For example, the rediscovery, translation and philological validation of classical texts written in Greek, Syriac and Arabic into Latin (the common language of Europe's educated elites) took place in cycles over several centuries (Montgomery, 2000). Along with commentaries, critiques and additions from famous medieval Islamic philosophers this ancient heritage of written knowledge eventually became accessible in printed form, when it took a leap forward to become a more diverse set of representations, analyses and recommendations for investigations into the natural world (Johns, 1998). That plateau in knowledge formation depended upon the diffusion of helpfully illustrated printed books embodying perspectives derived from Renaissance art which formed the basis for conversations, correspondence, associations and debate among Europe's growing numbers of natural philosophers and theologians dissatisfied with or sceptical of revealed spiritual truths (Rossi, 1970). This 'vital few' connected (by way of correspondence in Latin and the publication of books) into 'Republics of Letters' became more interested in the workings of God's natural world and in the possibilities for its control and manipulation (Rossi, 2001 and Field, et al., 1993). They widened agendas for discussion and education to include a range of natural phenomena including the age, size, shape, geography and limits of planet earth, movements of the sun, moon and stars, seas and their tides, climates, earthquakes, minerals, chemical substances, soils, plants, animals, fish and

human bodies. They engaged in debates concerned with mathematical and rational methods for the study of medicine, law and even theology, which coexisted in a hegemonic but uneasy relationship with natural philosophy.

That tension became more fraught during the Renaissance when printing improved and another cycle of humanist scholarship recovered and extended the range, validity and accessibility of competing classical texts which opened up a wider range of discourse about the nature and operations of God's universe (Long, 2001 and Henderson, 1991). That wave of classical scholarship not only questioned Aristotelean natural philosophy as expurgated and beatified by the church, but came dangerously close to challenging the logical and evidential basis of revealed truths about the world contained in the scriptures and other sacrosanct texts propounded by theologians in the service of the Roman Church (Rabb, 2006).

Thereafter irreversible and fundamental changes in a cosmography embodied in the cultures of European elite (in line with developments anticipated and cautiously outlined by a minority of precursors during the Middle Ages) became loud, clear and more extended and powerful. That conjuncture has been marked historiographically by the lives of Copernicus (1473-1543) and Newton (1642-1727) when a range of innovative 'discoveries' in Europe's intellectual history controversially labelled as a 'Scientific Revolution' came on stream (Gaukroger, 2006). The period also witnessed the discovery of a new continent, the division of Christendom into Catholic and Protestant countries and communities, horrendous wars over religion, the consolidation of regular transcontinental commerce by sea with Africa, Asia and the Americas, as well as extensions to the range, depth and potential of knowledge about the natural world. This eventful conjuncture has also been contentiously but plausibly configured by historians of Europe to mark a discontinuity in world history when cosmographical foundations for the reconstruction of a new regime for the accumulation of useful and reliable knowledge began to actively promote a latent intellectual and cultural potential for the support of sustained economic growth. In time, an ultimately more productive cosmography and regime came into being (Dear, 2006). It embodied

eastern as well as favourable western antecedents (Bala, 2008). Its development was neither revolutionary in pace nor linear in tend. Its historically validated connexions to an ongoing but gradual process of innovation were for many decades confined to a limited range of technologies that in time became useful and reliable for navigation by sea, the surveying of space, the derivation of energy from water, atmospheric pressure and steam power for drainage, the accuracy of artillery, the magnification of sight, the bleaching of textiles, etc. (Mokyr, 2002).

The list of direct connexions is not long. Debate over their nature and economic significance has been protracted and remains unsettled. Nevertheless, the contention of this essay is that the significance of this famous conjuncture for narratives concerned with divergence between the economies of the occident and the orient resides essentially in an unmeasurable, but unmistakeable impetus it provided for the formation of confident conceptions among Europe's educated and wealthy elites that the natural world was in process of becoming more intelligible and manipulateable for material gain and human health than their ancestors living in Roman and feudal times had ever imagined (Dear, 2006).

Unfortunately that impetus which approximates to a *gestaltshift* in the conceptions and perceptions of western elites cannot be easily, let alone conclusively, validated because historical evidence for its emergence and adolescence consists essentially of books written by famous names in the histories of science technology and cosmography which have been subsequently selected as contributions to the development of plethora of specialized disciplines that matured to become functional for the development of the natural sciences (Cohen, 1994).

Attempts to validate this hypothesis statistically have, however, produced some positive but inconclusive results in the form of a dramatic rise in the numbers and discernible decline in the prices of printed books published between 1450-1750 in western Europe following the invention and diffusion of the printing press (Van Zanden and Prak, 2013). Unfortunately the evidence for the numbers of books or

printed words devoted to or relevant for a reformed cosmography for the study of nature has not been measured. Presumably that trend was also upward (Headrick, 2000). Thanks to the internet we are, however, beginning to date and measure changes in the publication of a range of key words associated with new and more efficient modes of investigation into nature, including such terms as invention, discovery, experiments, facts, evidence, hypotheses, as well as other terms that evolved into concepts and vocabularies for the natural sciences (Wootton, 2015). Flows of published knowledge representing a reformed cosmography was almost certainly rising rapidly during a period when students attending universities and taking a compulsory course or two in natural philosophy was also increasing faster than populations at large (de Ridder-Symoens, 1996). Nevertheless, the case that flows of knowledge about the operations of a natural world that became steadily more accessible and intelligible to educated Europeans after, say 1450, were widely read, understood and perceived to be superior and potentially more useful and reliable than the knowledge available and accepted as adequate enough for their needs and aspirations by previous generations remains almost impossible to demonstrate. Thus an argument for cultural shifts in the cosmographical beliefs of an increasing and relatively significant proportion of educated Europeans can only be made on *a priori* and probalistic grounds and with reference to the beliefs that their counterparts and ancestors held about their natural world and prospects for its control before 1450, compared to, say 1750 and/or by elites in China, India, Islamdom, Japan and the Ottoman dominions in early modern times (Gaukroger, 2010 and Wootton, 2015).

One core component of the discourse about nature remained hegemonic. It was dangerous to challenge Christianity's foundational belief that the universe had been created by God; that operations of its celestial, terrestrial and biological spheres were divinely ordained, regulated and suspendible; and that mankind's primary purpose was to live but a short interlude on earth according to moral principles enunciated in sacred Christian texts as interpreted by God's one and only true Roman Catholic church. The hierarchy of that religion had, moreover, ordained that if men wished to understand the operations of a divine natural word

they should first seek guidance from the Scriptures. Alternatively they could consult a rather restricted range of licensed classical authorities: first and foremost Aristotle on anything but particularly on logical ways of comprehending the universe; Ptolemy on the heavens and solar system, Galen on the human body, Hippocrates on medicine, Pliny on plants and animals, Euclid on mathematics, etc. (Bona, 1995).

Centuries passed before Europe's traditional belief system (monotheistic Christianity compounded with classical views of the natural world) became permeated, let alone secularised, by a scientific cosmography. Before the age of enlightenment, elite cultures changed slowly. Religions adapted and progress could certainly have been assisted by the emergence of possibilities for appealing to the authority of diverse classical authorities other than Aristotle - particularly to Plato, Archimedes, Lucretius and Epicurus (Gillespie, 2008). Paradoxically the worldly and politicized hierarchy of the Catholic Church advised by Jesuit intellectuals acted from time to time as a buffer against fundamentalist attacks on the diffusion of knowledge that endangered 'truths' about nature as revealed in Christianity's sacred texts (Worcester, 2008 and Feingold, 2002).

Although and overall a positive view continues to be taken of the role of the Reformation for the advance of science inflated claims from supporters of the Weber and Merton theses for the effects of minor protestant theologies (lumped under the ambiguous label of puritanism) for the accelerated diffusion of a reformed cosmography have been successfully qualified, if not undermined (Davids, 2013 and Rabb, 2006). That certainly seems to be the case when juxtaposed and weighed in the balance against the fundamentalism unleashed by the reformation and counter-reformation across Christendom when Europe's relapsed into the barbaric conflicts and zero tolerance that flowed from a theologically diverse and contentious range of beliefs (Cohen et al., 1990). Conflicts over religion may, however, have stimulated, the spread of an enlightened and scientifically functional agnosticism towards all theological pretensions to comprehend the natural world (Harrison, 1998 and Feingold, 2002).

Meanwhile, the fragmentation of the Christian Church created niches of tolerance toward the beliefs of Christian intellectuals who held antipathetic or even hostile views towards revealed truths. They included theologies espoused by protestant and dissenting religions that emerged to challenge the sovereignty of the unpredictable, if repressive, tolerance of the Catholic church and its uneasy Thomist compromise with classical natural philosophy (Davids, 2013 and Grant, 2004).

Slowly but surely Christian Europe made personal and institutional spaces for a cosmography within which two kinds of truth co-existed: spiritual – which became matters of ritual, revelation and faith – and secular, which operated with a more rigorous and theoretical conception of nature; with observed and calibrated data, mathematical logic and probabilities; above all, with controlled and transparent experimental methods utilizing instruments that extended the power of the senses to augment flows of useful and reliable knowledge about the operations of the natural world (Bedini, 1999 and Cohen, 2010).

By 1750 and in contrast to their ancestors, a majority of educated Europeans supported what had matured into a tradition of state and private investment in voyages of discovery and inter-continental exploration in search of new and potentially useful knowledge. Most believed the skies and heavens could be mapped and that their own planet earth displaced from the centre of an infinite universe, rotated daily on its axis and circled the sun along with all other planets. Within this infinitely expanded and reconfigured universe they recognized their own insignificance (Wootton, 2015 and Gaukroger, 2010). Man, his common sense and religious convictions were no longer the measure of all things. His sensory perceptions and understandings of nature were recognised as limited, but could predictably continue to be successfully extended by instruments in the service of speculations, hypotheses and controlled experiments, designed and monitored by 'networks of experts' with credentials and codes of conduct maturing into scientific disciplines (Lloyd, 2009 and Headrick, 2000).

These men had not only produced maps of the world and its seas and oceans with more mathematically precise coordinates for purposes of trade and navigation, they were using telescopes to map the skies for similar utilitarian purposes. After decades of inconclusive investigations into the control of flowing water and the pressures and weight of air, they had also discovered new sources of energy with potential to be developed, harnessed and diffused for production (Inkster et al., 2004). In the course of a protracted intellectual conflict between 'ancients and moderns' marked by 'battles of the books' the traditional authority and appeal of classical authorities (particularly Aristotle, but including Ptolemy, Galen and Hippocrates) had been effectively degraded by the systematic exposure of their errors, by geographical discoveries, by solar observations with telescopes and by the elevation of mathematical logic and experimental methods into hallmarks for new and more productive ways of accumulating reliable and useful knowledge about the natural world (Levine, 1991, Smith et al. 2007 and Cohen, 2010).

Truths about God's divinely created and ordered natural universe revealed in new and old testaments, scriptures, epistles and other canonical texts and commentaries continued for centuries, however, to be less easy to subvert, even for a pluralistic Christendom. Although parts of orthodox Catholic beliefs about nature were simply rejected and others reconfigured as allegorical, the successful and protracted resistance of Christian religions contained the dissemination and limited the power of a purely secular scientific cosmography and culture. Traditional and revealed truths about nature were, however, circumvented by a reconfigured metaphysical basis for the representation and investigation of the natural world in ways that maintained and even strengthened Europe's competing versions of monotheistic Christianity. In effect that profound theological-cum-cultural conjuncture was taken forward by famous networks of Europe's Protestant and Catholic natural philosophers and mathematicians (Copernicus, Brahe, Galileo, Kepler, Pascal, Beeckman, Mersenne, Gassendi, Huygens, Boyle, Rohault and pre-eminently Descartes and Newton). Along with other intellectuals maturing into scientific philosophers they formulated and propagated a meta-theory that God had created a universe of natural phenomena composed of

corpuscles, particles or atoms that clustered when at rest or moved and interacted according to God's designs to operate, metaphorically speaking, like the mechanisms of clocks and automata. Fortuitously the core assumption of this view also embodied key elements of a universe reducible to atoms with prestigious antecedents contained in the speculations of some long forgotten but classical philosophers such as Lucretius and Epicurus (Randles, 1999 and Olson, 2004).

Christian elites gradually accepted the metaphysical notion of a God who had created and designed his universe on rational principles which he could revoke, but rarely did. God's designs for nature were, moreover, perceived to be accessible to investigations, deploying: mathematically rigorous models for the formulation of questions and (critically for empirical validation) an array of instruments constructed by craftsmen for the conduct of controlled and transparent experiments. Historical research has elaborated upon evidence that shows that among Europe's elites this image of a rational and intelligible universe created by their very own God became plausible enough to promote an extensive and professional interest in investigations into the probable and predictable regularities of the natural world. A proliferation of urban associations were formed and met to comprehend and debate these natural laws. They became networks to provide patronage for those who took the risks of exploiting their productive potential (Mokyr, 2017). Gradually, and from its religious origins and unpromising hermetic antecedents in astrology, alchemy and spurious pharmacology, natural philosophy forged connexions with craftsmen and moved on from its Aristotlean and classical origins, and spawned systemic paradigms and procedures for research within which post Newtonian western astronomy, physics, mechanics, chemistry, botany, geology and eventually even medicine, produced flows of increasingly reliable and widely diffused useful knowledge (Cohen, 2010 and Bona, 1995).

For economic development, apart from a significant and well documented history of experiments concerned with the properties of atmospheric pressure, with magnetism, with acids, human anatomy and navigation, clear and direct links

between Europe's reconfigured and extended investigations in natural philosophy to breakthroughs in technologies for agronomy, mechanical engineering and bodily health have proved difficult to document in ways that might convince sceptics who continue to insist that such connexions were tenuous, socially constructed and conceivably ran the other way (Mokyr, 2017). To bolster their constructivist, sociological and relativistic approach they have, however, also published confusing evidence that many acclaimed natural philosophers including Galileo, Hooke, Boyle, Beekmans, Huygens and Newton had continued to engage seriously, not only with their respective religions which is indisputable, but also with claims to knowledge from alchemists and astrologers involved with the unsystematic and unexplained manipulations of materials and natural sources of energy for sale to gullible customers and powerful patrons (Smith, 1994). Revelations that many scientists of the period were Catholics or Protestants and/or involved with occult and hermetic thought could, however, be represented as a felicitous way of reconciling (pace Newton) science with religion (Iliffe, 2017). In any case historians now recognize that the fantasies or 'experiments' of alchemists and observations of astrologers contributed to debates about scientific ways of knowing and understanding how the natural world really worked (Eamon, 1994, Newman et al., 2001 and Moran, 2005).

Over the long run, direct connexions between Europe's tradition in natural philosophy maturing into science allied to technological innovation became unmistakable (Noble, 1997). Global economic history's concerns have, however, been latterly with economic divergence between the occident and orient. In the absence of bodies of secondary literatures comparable in volume, scope and sophistication to recent historical analyses of European science, religions and cosmography, it may not be premature to accept Joseph Needham's insights and conclusions published two generations ago. As a Christian Marxist of unsurpassed erudition in global and in socially constructed histories of science and technology, Needham also remained deeply aware of the significance of the fortuitous but ultimately fortunate religious and classical antecedents and foundations for

Europe's peculiar but promotional cosmology for the accumulation of useful and reliable knowledge (O'Brien, 2009).

Furthermore, global historians may need to be reminded that Herbert Butterfield saw Europe's 'scientific, agrarian and industrial revolutions as forming such a system of complex and inter-related changes that in the lack of a microscopic examination, we have to heap them altogether as aspects of a general movement' (Butterfield, 1949). Butterfield's view could never develop into the kind of history that might appeal to most economists. To be elevated into the key chapter for narratives of divergence it could only be tested for plausibility by way of reciprocal comparisons with the cosmographies and regimes for the production, development and diffusion of useful and reliable knowledge operating in Islamdom, China and India in pre-modern times?

Of course, to paraphrase Elman, intellectuals from Oriental cultures continued to be engaged in endeavours to understand the natural world on their own terms and in their own ways (Elman, 2005). Nevertheless, that stance does not address the question of how effectively their scale and modes of engagement became for the discovery, development and diffusion of technological, institutional and biological innovations leading to sustained rises in standards of living, security and welfare for the populations of Asia and other continents. The question cannot be dismissed, either as Eurocentric or more seriously, as anachronistic. The evolution of 'cultural' dispositions towards innovation displayed by the political, economic and intellectual elites managing early modern Asian societies continues to be plausibly represented as embedded in cosmographical traditions of belief and epistemological thought that appear *prima facie* to be less conducive, indifferent or even hostile to systematic investigations into nature – albeit for entirely explicable historical, political and economic reasons (Sivin, 1995 and Hart, 2012).

Unfortunately only an entirely limited range of secondary historical literature is currently in print for the construction of a comprehensive academic surveys of the beliefs of elites and institutions of countries concerned with the properties and

potential of their environments to sustain and improve the welfare of populations residing in south, west and central Asia (McClellan et al., 1999). At present the only prospect for an intellectual engagement in reciprocal comparisons with the evolution of Asian beliefs and institutions concerned with nature that is comparable to and coterminus with the conjuncture in the culture of western European elites that occurred between 1543 and 1727 can be read in histories for imperial China (Ronan, 1983 and Temple, 1998).

Thanks largely to the Needham programme for the History of Science and Civilization in China, there is now a range of secondary literature in English (including a scholarly debate on Ming and Qing cosmographies) that has become extensive, diverse and sophisticated enough to allow for tentative comparisons with Europe. Predictably that aspiration had and will doubtless continue to provoke familiar post-modern objections. It will be condemned *ab initio* as designed to convey a reification of Europe as the sole locus for historical advances in science and technology or confronted by more sophisticated arguments concerned with the deployment of comparative methods for this complex sphere of history (Livingstone, 2003 and Sivin, 1995).

That is not, however the view taken by almost all scholars with the linguistic and scientific credentials required to debate the "Needham question." Most apparently accept his view that compared to earlier dynasties (particularly the Song) flows of innovations for the formation of useful and reliable knowledge faltered sometime after if not before 1500 (Bodde, 1991 and Bray, 2000). Thereafter Chinese contributions can be plausibly discussed not as stasis but rather as a history of relative retardation. No consensus exists, however, as to when and why a climacteric emerged and persisted during the Ming and Qing dynasties although constructivist and cultural narratives continue to reject the salience or even the relevance of contrasts with western Europe and draw reductionist and unidirectional explanations based on differences in modes, systems and levels of production (Lin, 1995).

For example, the share of the empire's population located in towns and cities regarded as hospitable locations for the formation of the human capital and institutions required to engage with scientific and technological innovation declined from a 20% level under the Song dynasty and by 1700 had fallen well below the ratios estimated for the advanced economies of Europe (Rosenthal and Bin Wong, 2011 and Von Glahn, 2016). As if not even more plausible is the argument that from the empire's stock and flows of men with the education, skills, talents and motivation required for the discovery, development and diffusion of useful and reliable knowledge, a high proportion misallocated time and kin money on the credentials and qualifications prescribed by the Chinese state for entry into and advancement within a bureaucracy recruited on merit as displayed in a competitive and empire-wide examination. The curricula for this admirably meritocratic system which persisted dynasty after dynasty exercised a dominant influence on the mission, form and content of all types of education undertaken by Chinese males beyond levels of basic literacy. Higher education was, moreover, regulated by and for the state to serve two other purposes deemed to be more essential for the governance of an extensive and complex empire. The first was to endow its mandarinate of officials with the prestige and authority derived from their status as a loyal and incorruptible bureaucrats, implementing the decrees and orders of an emperor whose power to rule over the heterogeneous populations and territories of a vast empire was widely proclaimed as a mandate from the heavens (Elman, 2000). The main objective of imperial China's tightly regulated systems of higher and secondary education was to clarify, disseminate and debate how a set of interrelated moral principles enshrined in venerated ancient texts for the governance of an extensive complex and agrarian empire could be internalized into personal and social behaviour. The empire's classical texts (as Jesuit missionaries to the empire appreciated) can be plausibly represented as analogous to the canonical texts of Christendom, including the bible, the new testament and lives and writings of saints – Europe's equivalent of the wisdom of China's sage kings. Over centuries that predated the birth of Christ by way of commentaries, critiques, adaptations and the selective absorption of elements from rival systems of belief including Buddhism, Daoism and Mohism the secondary education for the

elites of Ming and Qing China became consolidated into a powerful ideology for righteous behaviour framed by the writings of Confucius which is conventionally referred by intellectual historians as Neo-Confucianism (Barry, 1981, Genet, 1998, Elman and Woodside, 1994).

Neo-Confucian philosophy dominated the syllabus for the imperial examination system and curricula for the education of China's elites. Neo-Confucian texts studied, memorized and analysed using philological methods, by the best and brightest young minds in China instilled a quasi-spiritual reverence for ancient authorities including Mencius and Laozi and particularly Confucius (Elman, 1984 and Elman, 2005).

China's traditional 'wisdom' may be understood as providing the basis for an education in moral and political philosophy that inculcated the virtues embodied in the cultivation of personal enlightenment through humanistic and didactic forms of scholarship and, above all, through respect for and compliance with hierarchy reposed in patriarchy within families administratively in a mandarinate and politically in dynasties of emperors mandated from heaven who were served by officials exercising paternal and moral rule over a largely illiterate population of an agrarian empire (Jensen, 1997 and Xinzhong Yao, 2002).

From a Eurocentred perspective, the content of Chinese education, the forms of teaching adopted by institutions for secondary and higher education and the absence of a tradition of disputation amongst masters and students; the tiny numbers and restricted range of institutions for technical and commercial education as well as the systems enlightened but overwhelming concerns with personal behaviour, social stability and political order seem *prima facie* to be less than encouraging towards the study of investigations of the natural world than *prima facie* appears to have been the case for the cosmography evolving in medieval and early modern Christendom (Lloyd and Sivin, 2002).

Nevertheless, it could be erroneous to conclude that knowledge that was useful and reliable for the comprehension, control and manipulation of the celestial, terrestrial and biological spheres of that world had not accumulated at a more impressive rate in the Chinese empire than in western Europe before, say, 1500 or that it lapsed into stasis thereafter. Historical research is currently and correctly focused on the analysis of two historical trajectories one of which (and to some significant degree) experienced a conjuncture in its pace and direction, while the other did not (Needham, 1969, Sivin, 1995 and Elman, 2006).

Chinese intellectuals certainly continued to produce and publish useful and reliable knowledge in Ming and Qing times. Only a minority of the empire's educated literati obtained posts in the bureaucracy. Furthermore, many of those privileged scholar officials who did found it necessary to acquire some practical knowledge of agronomy, meteorology, hydrology, pharmacology and medicine. Among growing numbers of men (literati) educated in Neo-Confucian philosophy and statecraft of those who failed to obtain posts in the bureaucracy, an unmeasured proportion wrote numerous treatises, manuals, entries for encyclopaedia on the properties, uses and purposes of 'things' such as drugs, copper, coinage, porcelain, lacquer-ware, textiles, dyestuffs, birds, sugar, salt etc. They consulted craftsmen who they regarded as their intellectual inferiors in order to publish specialized and ostensibly useful knowledge of many 'things' (gewu) as well as speculations about the 'concrete forces' embodied in natural gas, wind, rain, sound, light, magnetism etc (Ropp, 1990, Elman et al., 1994, Elman 2006 and Schaffer, 2011).

The pursuit of potentially practical knowledge was, however, neither rewarded with prizes from the state nor privately patronized on any scale protected for purposes of individual material gain by patents for monopoly. That knowledge was not, moreover, regarded as anything like as prestigious as classical forms of learning that contributed to harmonious family life, to stability for the social order and, above all, for the benign governance for a huge pre-modern empire (Henderson, 1984 and 1991 and Schaffer, 2011). *Prima facie* the empire provided

almost no support for a separable intellectual role with its own autonomous intellectual base that enjoyed social and political prestige for systematic and sustained interrogations of nature. To a degree that represents a significant contrast with Europe, the research, development diffusion and storage of knowledge concerned directly with the operation of the celestial, terrestrial and biological spheres of the natural world was conducted by literati and officials employed by, for and under the aegis of the state (Montgomery and Kumar, 2016).

By late Ming times a minority of literati began to question the hegemony and utility of traditional classical learning and sought with limited success to redefine the political, social and cultural status of more practical and material forms of knowledge including knowledge imported into China, as artefacts, industrial technologies as well as the new mathematics, astronomical methods and observations communicated by Jesuit missionaries and European merchants (Brook, 2010 and Schaffer, 2011). Nearly all proposals for reform were predictably resisted by scholar officials concerned to protect their own status and cultural capital. Under the Qing reformers could be persecuted. Their books could be and were proscribed and burnt. Generally they failed to convince the political establishments of either the more flexible Ming regime or the alien Manchu dynasty (who conquered the empire between 1636-83) to modify let alone overturn Neo-Confucian ways of thinking about the world as an interconnected and harmonious cosmic and moral order that included the heavens, all things on earth including man and his organic relations with nature. After all the development and dissemination of that cosmography had for millennia served efficiently as an ideology for the maintenance of centralized rule by a long succession of dynasties (Wright, 1957, Henderson 1984 and Johnston, 1995).

There seems to have been (as some revisionist historians have recently claimed) lost moments and promising opportunities for reform to the ways that China's talented and educated elites conceived of ways to encourage more systematic ways of interrogating the natural world under late Ming emperors (Zurndorfer, 2002, Jami, et al., 2001 and Schaffer, 2011). Greater attention, reflexion and respect

might have been paid to western knowledge that unfortunately only became accessible to China's literati through the less than objective conduits of a small coterie of Jesuit missionaries educated in western natural philosophy and resident at court (Elman, 2005). Restraints on learning through imports and import substitution may well have been a far more serious constraint on the formation of useful and reliable knowledge (Jami, 2001). Perhaps the takeover of the empire by an alien dynasty anxious to secure legitimacy by suppressing departures from classical Chinese traditions of thought as misplaced, degenerate and potentially destabilizing can be plausibly represented post hoc as an obstacle to the relocation and reconfiguration of ways of investigating the natural world in new and potentially more productive ways? (Leonard and Watts, 1992, Smith, 1994 and Shruve, 2004).

Given that it is now generally recognized as erroneous to under-estimate the contributions made by Chinese intellectuals and craftsmen to long term advances to knowledge formation for global science and technology before c.1500, Eurocentred historians of that all-important sphere for the promotion of the study of nature and material progress can only observe another high level equilibrium plateau, the penalties embodied in an early start and an unfortunate change of dynasty (Henderson, 1984 and Elman, 2006). Nevertheless as historians of the Chinese book have demonstrated, encyclopaedias, manuals, almanacs, tracts, maps etc. continued to be printed in China within the framework of the empire's traditional cosmography that remained virtually unchanged until the fall of the empire in 2011 (Baten and Van Zanden, 2008). On a per capita basis the volumes of books and other publications printed in Europe seems, however, to have been significantly higher (Buringh and Van Zanden, 2009). Historians who have examined the range and contents of publications that appeared under the Ming and Qing dynasties have, however, convincingly demonstrated that some share of the topics and themes that appeared in print could be listed under the western category of useful and reliable knowledge (Zurndorfer, 2002). On closer and contextualized examination by experts in the histories of science and technology some (but as yet unknown proportion) of this potentially useful knowledge could

conceivably be found to be innovatory contributions to an evolving scientific discipline or technology. Some knowledge originating in late imperial China must have diffused into Europe.

At present, encyclopaedias for the global histories of sciences and technologies designed as references to flows of innovations that emerged after 1500 are dominated by discoveries, inventions and ideas that emerged in the Occident (Murray, 2003). Yet there must also be room in the divergence debate to question Eurocentric views that China's talented literati and craftsmen made almost no contributions to advances in sciences and technologies after the 15th century? (Qian, 1984 and Murray, 2003). As the Needham programme has demonstrated, Chinese intellectuals had certainly discovered and accumulated a great deal of useful and reliable knowledge and observations about the natural world long before Europeans embarked upon a more intense, sustained and innovatory quest to comprehend its operations largely for purposes of material gain and geopolitical power; a quest which fortuitously strengthened their religious convictions that investigations into nature revealed God's creation to mankind. Far away and for centuries Chinese intellectuals had promoted the accumulation of knowledge within parameters of an entirely different cosmology that *prima facie* had no connexions with any belief in eternal salvation and seems to have been far more flexible and less intolerant towards notions of discovery than Christendom with its theology of revealed truths, conveyed and interpreted and enforced by hierarchal religions (Henderson, 1984 and Vogel, 2010). Nevertheless, Europe's long term record of success in comprehending the forces of nature became undeniable (Murray, 2003). Furthermore, and given that China's political and educated elites eventually adapted similar modes of investigation and institutions for the discovery, development and diffusion of useful and reliable knowledge later rather than sooner there could be nothing better than the *sui generis* argument for not engaging with Needham's Eurocentred views of the potentially negative influences exercised by the cosmographical framework and epistemological ways in which studies and investigations into the natural world took place in Ming and Qing imperial times (Huff, 1993, Sivin, 1995 and Elman, 2006).

Needham's classical status in the history of late imperial China's institutions for the discovery, development and diffusion of useful and reliable knowledge continues to command the high ground and set the agenda for scholarship in that complex field of history (Needham, 1969, Nakayama and Sivin, 1973, Elvin, 2004, Elman, 2005). Nevertheless, several features of the cultural cosmographical and political foundations of Chinese science that he selected as responsible for its climacteric and relative decline compared with Europe have come under sustained scholarly criticism.

At the forefront is a critique of the Eurocentred liberal view that financial support for the higher levels of education required and conduct of systemic investigations into the operations of the natural world could only have emanated, in large part, from an imperial state with its own predictable priorities for expenditures on the propagation of an ideology that could secure compliance across the empire with its prudential fiscal demands for sufficient revenues to fund policies to maintain internal order, external security and tolerable levels of subsistence for its subjects (Bin Wong, 1997). For these purposes the state embraced, maintained and, where necessary, imposed a curriculum for state and private forms of higher education that certainly allowed for investigations into things and matters that could be of practical use, but which were nevertheless dominated by a didactic moral and political philosophy that had served to maintain the unity and stability of the empire (Nakayama, 1984 and Qian, 1984). In short, China's regime for the definition, formation and diffusion of useful and reliable knowledge was directed to serve the core concerns of the imperial state. (Leonard and Watts, 1992).

This does not imply that either Ming or Qing governments failed to establish and sponsor institutions (bureaux) for systematic investigations into a variety of practical and utilitarian concerns for its subjects in such areas as hydrology, agronomy, agriculture, transportation, meteorology, cartography, the production of salt, porcelain and alum, astronomy etc., (vide references to Brook and Elman). Furthermore, although the imperial government acted from time to time to censor, repress and destroy books that confronted its ideology for social harmony and

political stability, it allowed and even encouraged its officials and accredited literati to publish manuals, almanacs, gazetteers and sections of encyclopaedias on an increasing variety of potentially useful things that historians of the Chinese book and Chinese science have catalogues as evidence to qualify an impression of historical and relative decline emanating from Needham's programme to inform a mainstream Eurocentred historiography for the global history of science (Nakayama and Sivin, 1973 and Arrault and James, 2001).

Mark Elvin has, moreover, observed that among reams of printed publications that appeared in Ming and Qing times are examples of every style and mode of scientific enquiry published in western Europe during the penetration of its cosmography by a Scientific Revolution. (Elvin, 2004) This evidence commands respect and nothing of comparable potential seems to have appeared in other oriental empires. (Parthasarathi, 2011, Reinert, 2013 and L.S.E. Department of Economic History Research Project, URKEW, 2008-13).

Nevertheless, Eurocentred perceptions of the scale and scope as well as the intellectual and economic significance of Chinese endeavours to accumulate useful knowledge remains valid. This historiography maintains that path dependency had placed and continued to sustain the beliefs held and institutions supported by the Chinese state and its talented elite of educated intellectuals on a trajectory for the discovery and diffusion of a scientific knowledge that understandably but discernibly looks inferior for scientific and technological progress than the regimes operating for that purpose in the polities of western Europe around the same time.

Alas, and for reciprocal comparisons there are major aspects of China's libraries of books of evidential research into things that have not yet been analysed. How much of it developed into useful and reliable knowledge for purposes of production? Was it accessible, cheap to acquire, widely read, critically appraised among elites with relevant expertise in diverse fields of knowledge and developed with artisans who possessed the skills required to transform hypotheses about "nature" into operational techniques and technologies? No claims have been made

from an admittedly limited amount of research in print that the process of development from propositional knowledge that flowed from investigations into and publications about material things in China was particularly effective for the promotion of economic growth (Xu, 2016). On the contrary, the process of diffusing, illustrating and conveying such knowledge to those directly involved in mining salt, manufacturing cottons, dyeing silks, smelting metals etc. seems to have been deficient in several respects, not least because investigations and publications about material things occupied a limited space and low status compared with commentaries on and revisions to texts in neo-Confucian moral philosophy. Their authors appear to have struggled for credibility and attention (Needham, 1969, Nakayama, 1984, Kim, 2010).

Furthermore, the epistemology deployed for evidential research and publication also appears *prima facie* to have about as promotional for the development of modern science in China as scholasticism had been for its development in Europe before Aristotlean and Thomist Ideas were degraded (Huff, 1993, and Adshead, 1995). China's philosophy-cum-political ideology for a large, complex and successful empire remained more resistant to change the veneration for its classical foundations permeated the curricula for the education and mind sets of elites who ran the empire. A majority preferred to read and study classical and canonical texts which remained established as the context and source for the validation of references and recommendations derived from published investigations into things and nature (Jensen, 1997 and Vogel, 2010).

For the discovery, development and diffusion of useful and reliable and potentially productive knowledge, the empire's Confucian cosmography could be read as tolerant towards the investigation of things that could be located within a Confucian cosmography that in contrast to the cosmography evolving in the west conceived of man as part of nature and nature as one harmonious whole in which man and things in the environment in which he existed could be represented and correlated through the presence of such classical concepts and vocabularies as dao, li, qi, ying and yang (Yang, 1990). Historians whose erudition and scholarship

commands nothing other than respect have established that Chinese intellectuals continued to pursue the accumulation of useful knowledge on their own terms and in their own ways in Ming and Qing times. Their rejection of Eurocentric representations of such endeavours as a misplaced unprogressive and conservative reactions to the rise of western science and proliferation of scientific disciplines is well taken professional history (Elman, 2005, Zurndorfer, 2002).

Nevertheless, they have not undermined the salience of the Needham questions or his sympathetic critique of Chinese beliefs reflected in the epistemological ways and concepts that they deployed to comprehend the natural world. Unlike their European counterparts generations of Chinese intellectuals entertained no belief in universal and reliable laws of nature that could be revealed either by systematic observations, mathematically based deductions from axiomatic premises and methods or any other modes for the comprehension of nature's truly awesome complexities (Cohen, 2010). Generation after generation they retained faith in a belief that for all eternity the heaven (Tian) had established cosmic forces (Li and Qi) that over time operated to include and sustain a benign natural environment for mankind through the interactions of two active and responsive forces (yin and yang). These forces maintained harmony among and between the celestial, terrestrial, biological, social and political spheres of the middle kingdom. Their operations could be defined, observed and correlated as movements away from and towards a state of balanced equilibrium. Anomalies could be observed in the skies and interpreted astrologically as warnings or omens that the political policies pursued by the rulers of imperial China under mandates from the heavens could either be harmful or alternatively successful for the harmony of the empire (Peterson, 1980).

Compared to western Europe at its core, the cosmography that influenced the development of useful and reliable knowledge in the Ming and Qing empires was dependent upon and strongly influenced by the need to maintain the unity and stability of a large and complex empire. As an ideology it can be represented as successful. As a basis for the formation of knowledge and attitudes that penetrated

into elite cultures for the development of modern science and technological innovation, historians continue to depict the empire's cosmography as conservative and fatalistic towards prospects for the interrogation, manipulation and control of the natural world (Nakayama, 1984 and Kim, 2020). Within that cosmography thousands of things were studied on the presumption, as Needham observed, that they "behaved in a particular way not necessarily because of prior actions… but because of their positions in an ever-moving cyclical universe was such that they were endowed with particular natures that made that behaviour inevitable for them". Sympathetically he added that "the Chinese wise before their time had worked out an organic theory of the universe which included nature and man, church and state and all things past, present and to come". Unlike their European contemporaries they lacked any "confidence that the code of Nature's laws could be unveiled and read because there was no assurance that a divine being ever more rational than ourselves had ever formulated a code capable of being read' (Needham, 1962 and 1969). Along with most western scientists and the educated and wealthy elites of his times, England's great chemist and theologian, Joseph Priestley, would have agreed with Needham. 'If,' Priestley wrote, 'there were no laws of nature … there could be no exercise for the wisdom for the understanding of intelligent beings and no man could lay a scheme with a prospect of accomplishing it' (Rutt, 1817).

Yes, 10,000 things were analysed but within a cosmography that an eminent historian of Chinese science has recently been referred to as "a scattered landscape of individual reactions rather than a landscape of knowledge in the making" (Schaffer, 2011).

Is it simply Eurocentric to suggest that China's cosmography had been effective enough for the construction of a successful agrarian economy, but became increasingly less relevant for an empire confronting the demographic environmental, scientific and technological and geopolitical challenges that had emerged by the late Ming? (Cheng, 1977 and Juma, 2016).

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