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Why England and not China and India? Water systems and the history of the Industrial Revolution*

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Abstract

Global history has centred for a long time on the comparative economic successes and failures of different parts of the world, most often European versus Asian regions. There is general agreement that the balance changed definitively in the latter part of the eighteenth century, when in continental Europe and England a transformation began that revolutionized the power relations of the world and brought an end to the dominance of agrarian civilization. However, there is still widespread debate over why Europe and England industrialized first, rather than Asia. This article will propose an explanation that will shed new light on Europe's and England's triumph, by showing that the 'water system' factor is a crucial piece missing in existing historical accounts of the Industrial Revolution. It is argued that this great transformation was not only about modernizing elites, investment capital, technological innovation, and unequal trade relations, but that a balanced, inclusive explanation also needs to consider similarities and differences in how countries and regions related to their particular water systems, and in how they could exploit them for transport and the production of power for machines.

Studies that aim to explain the origins of the modern world must be concerned with limitations and possibilities inherent in different types of waterscapes and river basins. Discharge patterns, precipitation variations, and silt loads in rivers all matter, as do diverse water management traditions and dominant ideas about water and water control. These issues are crucial, because they strongly influenced the ability of governments and entrepreneurs to develop efficient transport systems and factory production. Although the Industrial Revolution relied on water for power and transport until the coming of the steam engine and the railways, comparative analyses of this transformative process have generally overlooked water landscapes, and water control achievements and traditions. By highlighting regional similarities and differences in complex and multifunctional water systems, it may be possible to

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solve some of the empirical and theoretical problems with dominant modes of explanation as to the origins of the Industrial Revolution.

The most influential explanations of the 'great divergence' between Europe and Asia share structural problems.[1] Theories that underline either European cultural and political uniqueness or European exploitation of 'the other' can explain hypothetically why Europe succeeded and Asia failed, but not explain simultaneously why England took the leading role in Europe, or why certain parts of western Europe industrialized before the rest of the world. A plausible explanation should not turn correlations into causal explanations but should distinguish between necessary and sufficient causes, causes and occasions, and causes and preconditions. Such an approach should also be exogenous, in the sense that fundamental technological and economic transformations need a causal element that does not itself require an economic or technological explanation. A convincing explanation should also make sense of the Industrial Revolution's gradual and regional character. Moreover, a useful account of 'the triumph of the West' must break away from an almost exclusive concern with the West, to the neglect of Asian economies and technologies. Recent research findings question widespread assumptions about fundamental differences in economic and technological levels between Europe and 'the rest', as well as between the modern and the 'traditional' West.

It is also essential to avoid a near exclusive focus on social variables, to the neglect of natural and environmental conditions. Instead, one needs to provide a nuanced view of how environmental conditions contextualized social interactions, and how political and social systems interpreted environmental contexts.[2] Since all societies at all times have had to relate to and control the waters that run through their territory, studying complex and multifunctional water systems is useful for analysing comparative patterns of development and transformation. This is especially so in the context of the first phase of the Industrial Revolution, when the water systems and the ways in which they were exploited underwent fundamental changes.

A complex and multifunctional water system is understood as consisting of three interconnected layers. First, physical form and behaviour includes precipitation and evaporation patterns, how rivers run in the landscape, the interface between rivers and sea (where applicable), and the development patterns and initiatives that these physical structures tend to encourage. The second layer consists of the human modifications of the physical water landscape, for a water system also reflects societies' ability or determination to manipulate their water. One important aspect of the Industrial Revolution was not only that water was used and controlled in new ways and in new economic sectors but also that water's multifunctional role in societies increased and deepened, as an aspect of modernity. The institutional and conceptual dimension of a water system is the third and final layer: that is, management practices and ideas about water and water control, which are only very briefly addressed in this article. 'River system' is used here to refer to how a river actually manifests itself

1 For this expression, see Kenneth Pomeranz, *The great divergence: China, Europe, and the making of the modern world economy*, Princeton, NJ: Princeton University Press, 2000.

2 Terje Tvedt, *The way the rivers run*, unpublished working paper for the Centre for Advanced Studies, Oslo, November 2008; idem, 'Bridging the gap: a water system perspective', in Willy Østreng, ed., *Transference: Interdisciplinary Communications*, Oslo: Centre for Advanced Studies, 2009.

in society, reflecting the complex combination of physical and social variables that influence a river's behaviour. These include not only physical aspects, such as rainfall, evaporation, topography, tributaries, soil types, discharge, and sediment transportation, but also alterations due to human interference.[3] G. W. Skinner suggested dividing China into eight distinct regions, ending up with river basins as a decisive descriptive criterion.[4] A complex and multifunctional water system is a much broader term than a river basin, but it buttresses the notion that regions, rather than countries, are often the most appropriate units of comparison. This article presents some data from a comparative research project of developments of the industrializing regions of England and of the core economic regions of India and China– that is, the great river valleys of the Brahmaputra/Ganges system, the Indus, the Yangtze, and the Huang He, for the period 1760–1820.

The emphasis on the need for a comparative analysis of complex and multifunctional water systems in order to understand regional and global transformations of the late eighteenth and early nineteenth centuries is not an attempt to manufacture a single-cause and deterministic hypothesis of the Industrial Revolution. This perspective does not imply criticism of analyses that deal with overarching and interconnecting trends in economic relations between Europe and Asia, or of cultural and ideological traditions, but provides a new context, in which such issues can be studied comparatively. At the same time, emphasis is given to additional variables, which have so far been neglected in the literature. This article argues that it is necessary to understand how different water systems created different possibilities for the development of trade and industries, without in any way claiming that the Industrial Revolution was predetermined to happen when and where it did. Innovative British entrepreneurs were not historically inevitable, but it is argued here that, whatever the strengths of market orientation, capitalist mentality, or investment capital, similar entrepreneurs could not succeed in the core economic regions of China, India, or other European countries of the time, because of the character of their water systems.

Transportation and water systems

Transportation has been widely recognized as a crucial factor in the Industrial Revolution, and there is little doubt that waterborne transport was most important for the new industries. Transportation systems encouraged commercial expansion, facilitated the division of labour, and linked production to markets. Until the middle of the nineteenth century, rivers and canals were essential in deciding which regions and cities could trade with each other, and where industry could profitably be located, coal mined, and iron refined. Most importantly, they allowed the shipment of heavy raw materials, such as iron and coal, from their extraction points to industrial sites. However, comparative studies of the Industrial Revolution have given waterborne transport too little attention, even though Adam Smith, in his *Wealth of nations* in 1776, recognized that industrial development depended on the

3 Terje Tvedt, ed., *A history of water*, 4 vols to date, London: I. B. Tauris, 2006–. For China, see Ch'ao-Ting Chi, *Key economic areas in Chinese history*, New York: Paragon Books, 1963; Mark Elvin, *The retreat of the elephants: an environmental history of China*, New Haven, CT: Yale University Press, 2004, pp. 115–65.

4 G.W. Skinner, ed., *The city in late imperial China*, Stanford, CA: Stanford University Press, 1977.

infrastructure of water transport. Nevertheless, some studies have shown the importance of waterborne transport for the development of Britain itself.[5] Deane put it like this: 'If Britain had had to depend on her roads to carry her heavy goods traffic the effective impact of the industrial revolution might well have been delayed until the railway age.'[6]

The importance of waterborne transport in the initial, decisive phases of the Industrial Revolution is underscored by the fact that most goods in pre-modern economies travelled by land, or on boats in coastal transport.[7] Road transport was generally preferred, because it was more reliable than inland water transport, despite roads often becoming impassable because of rain. Precipitation could be a nuisance year-round in parts of England, while in China and India the monsoon rains made large parts of the road network unusable, even for small-scale commerce and transport of light goods, on a regular basis and for months on end. But even where and when roads were passable, available modes of road transport could not satisfy the new demands that emerged during the eighteenth century. Only boats and barges could handle heavy raw materials such as coal and metal ores in large quantities, and transport them at an acceptable cost to emerging regional and global markets, together with lime, sand, manure, general merchandise, and agricultural produce. The development of the coal and iron industries, and the success of the cotton industry, depended upon improved transport facilities. Goods that previously could not compensate for the cost of transport were moved night and day on new water routes. Thus, comparative questions about water systems should focus on which countries or regions had a suitable physical water system, where artificial waterways could most easily be built to serve such purposes, and what entrepreneurs, engineers, and politicians had the experience, competence, and will to create such a transport network.

To the extent that transport systems have been compared in the literature on the Industrial Revolution and the 'great divide', the argument has been that, if anybody had an edge, it was the Chinese. It has been suggested that it 'seems very hard to find evidence of a European advantage in transportation'.[8] In contrast, the 'remarkable development of water transport' in China has been underscored: East Asia had an 'overall advantage in transport'.[9] Or again, China had a 'superb system of waterways'.[10] As Fernand Braudel wrote, quoting Father de Magaillans, 'No country in the world . . . can equal China in navigation.'[11]

5 J. Phillips, *A general history of inland navigation, foreign and domestic: containing a complete account of the canals already executed in England with consideration of those projects*, 4th edition, London: J. Taylor, 1803. See also Derek H. Aldcroft and Michael J. Freeman, *Transport in the Industrial Revolution*, Manchester: Manchester University Press, 1983; Rick Szostak, *The role of transportation in the Industrial Revolution*, Montreal: McGill-Queen's University Press, 1991; Gerard Turnbull, 'Canals, coal and regional growth during the Industrial Revolution', *Economic History Review*, 40, 4, 1987, pp. 537–60.

6 Phyllis Deane, *The first industrial revolution*, 2nd edition, Cambridge: Cambridge University Press, 1979, p. 76.

7 Fernand Braudel, *The identity of France, volume two: people and production*, trans. Siân Reynolds, London: Fontana Press, 1990.

8 Pomeranz, *The great divergence*, p. 35.

9 Ibid., p. 34, quoting Adam Smith, *The wealth of nations*, New York: Modern Library, 1937, pp. 637–8.

10 Pomeranz, *The great divergence*, p. 185.

11 Fernand Braudel, *Civilization & capitalism 15th–18th century, vol. 1: the structures of everyday life*, trans. Siân Reynolds, New York: Harper Row, 1979, p. 421.

However, comparisons should not treat navigability as a simple binary concept, based on kilometres of waterways, the extensiveness of a canal system, or the number of boats on waterways at a certain period of the year. When comparing the potential of different regions' rivers and canals and their role as trade routes in relation to the specific transport needs that emerged in industrializing economic sectors in the second half of the eighteenth century, many issues should be analysed, such as rivers' velocity, the height and frequency of rapids and cataracts, maximum and minimum flow, tidal versus non-tidal characteristics, peak current speed, annual and seasonal variations in water level, and silt and sedimentation load. Such factors decided the cost of transport, how many times the goods had to be loaded and unloaded, the regularity of the transport system, and the extent to which goods could be shipped all year round and both upstream and downstream. Furthermore, the water system determined the types of boat that could be used, and hence the weight and amount of goods that it was possible to transport.

River modification and canal-building were more dependent on local conditions than has been acknowledged in historical writings and in the travel accounts on which they often rely. A functioning canal needed an adequate supply of water for the summit level, and open canals (all of them at that time) depended on evaporation rates and on soil types that did not leak. Sufficient all-year water supply for the canals was the main problem in most areas, and was dependent on rainfall's seasonal variability, glacial melting, and the layout of river systems. Floods also washed away embankments, covered locks, and made access difficult. Moreover, the work and investment needed to construct and maintain artificial waterways were not only influenced by waterscapes but also by political relations among different users of rivers.

Additionally significant were the relative proximity of navigable rivers and canals to new sources of raw materials, and the character of the specific interface between seas and navigable rivers. It is also difficult to overestimate the importance of good and stable harbours close to a navigable river mouth for the cost and efficiency of loading and unloading seagoing ships. These factors, when combined, would decide the extent to which inland water transport was possible or sensible, or indeed economically viable at all. No systematic comparison of water systems and transport potentials in the major regions of Europe and Eurasia has been carried out in relation to the 'great divergence' debate until now. This article presents some data from such a research project, but focussing mainly on England, China, and India.

Water systems and transport in England

Compared to the core economic regions of China, India, Northern Italy, and France, England had a unique system of relatively easily navigable waterways, and waterborne transport had long been more reliable than road transport. Moreover, medieval water transport was cheap, for carriage by land could be ten times the price.[12] The rivers were fed by rain all year round, reflecting the regular precipitation pattern of this part of western Europe

12 Evan T. Jones, 'River navigation in medieval England', *Journal of Historical Geography*, 26, 1, 2000, pp. 60–82.

and resulting in little variations in water levels. What destroyed muddy roads made rivers navigable. Moreover, there were few rapids, and the waters carried little sediment and did not normally freeze during winter. On the coasts of the North Sea and the Irish Sea, there were estuaries with tidal rivers penetrating far inland, creating sea routes and land routes simultaneously, long before the advent of steamers able to travel upriver against the current. These small English rivers became the commercial lifelines of the medieval kingdom, encouraging early regional specialization and urbanization. They were remarkably reliable, especially compared to those of India and China, even though England experienced floods, droughts, and freezing rivers, which caused problems for the boatmen and for trade in general. Compared not only to India and China but also to France, in England it was easier to dredge rivers, reinforce banks, straighten and shorten river courses, and control water levels with sluices and staunches of modest size and complexity. The English water system was so benign that waterborne transport could to a large extent rely on natural rivers until the 1750s.

England also had a crucial advantage when it came to perennial water supply for small artificial waterways, for sea-level canals in moist areas had a high water table and most of the country had year-round rainfall. While Britain had very few proper canals in 1759, it has been aptly stated that 'the map of English canals, is the map of industrial England'.[13] In less than a generation, the whole face of England was furrowed with navigable waterways, and bulky goods were more and more often carried by boat. Canal boats in England could carry 30 tons pulled by a single horse, or more than ten times the cargo per horse using a cart. New technologies, notably the puddle-clay process, and new types of locks and boat lifts encouraged canal-building further.

The 'canal mania' of 1760–1840 gave high returns to a new class of shareholders. It has been argued that it even created a new kind of business mentality, or the 'true beginnings of financial capitalism', utilizing surpluses from agriculture and trade, and capital provided by manufacturers and other investors.[14] In England the technological, financial, and political challenges in canal-building were manageable by private entrepreneurs, while in countries such as China, India, and France the state was directly involved, because challenges posed by physical waterscapes were such that they could not be solved by individual citizens or small groups of businessmen. The canal system in England was developed into an interconnected web of fairly efficient waterways that could be used on a quite regular all-year basis. Very importantly, both coal and iron deposits were available within the ambit of the water transport system in England, to a much larger extent than in any other country. This made it possible for sources of raw materials to be linked to the production sites as well as to the market, and every city in England, except Luton, was connected to the sea by 1800. England

13 C. W. Crawley, *War and peace in an age of upheaval, 1793–1830*, Cambridge: Cambridge University Press, 1965, p. 38.

14 R. A. Bryer, 'Marx and accounting', *Critical Perspectives on Accounting*, 10, 5, 1999, p. 687; idem, 'The history of accounting and the transition to capitalism in England. Part 1: theory', *Accounting, Organizations and Society*, 25, 2, 2000, p. 158. See also Jonathan Barron Baskin and Paul J. Miranti, *A history of corporate finance*, Cambridge: Cambridge University Press, 1997, p. 127; Philip S. Bagwell and Peter Lyth, *Transport in Britain, 1750–2000: from canal lock to gridlock*, London: Hambledon, 2002, p. 12.

possessed 1,900 kilometres of navigable rivers in 1725.[15] By the end of the 1820s, the country had 3,400 kilometres of navigable rivers, and 3200 kilometres of canals.[16] Waterborne transport had thus become more crucial than ever, and bulk goods, such as coal and iron, could be transported at a much lower cost than by road.[17]

Water systems and transport in China and India

Chinese rainfall patterns caused extreme annual and seasonal fluctuations in river discharges, almost incomparable with European rivers, and in particular with those of England. Moreover, marked seasonality and long dry spells profoundly affected the availability of water for canals.[18] There were common and extreme variations in river water levels, and high rates of bank erosion and sedimentation. The colossal human efforts needed to protect societies against these physical characteristics of the local water systems translated into serious impediments to the development of transport infrastructure. Furthermore, runoffs from the principal river drainage basins are gathered into remarkably few main outlets to the sea in China, with only some five to six outlets for about 4,000 kilometres of main coastline to carry off enormous river discharges, fed not only by the monsoon but also by Himalayan glaciers. The characteristics of these widely separated river systems differed greatly, but they could all cause catastrophic floods and they all flooded very frequently. Commercial centres were worst affected, because they were often located close to the rivers and on vast, fertile delta plains, partly because rivers were the main transport arteries, at least during certain periods of the year.

Before the coming of the steam engine, river transport and a reliable trading system for bulk goods were further impeded by rivers changing their course over large distances and carrying huge amounts of sediment. Large river modifications schemes, running like a scarlet thread through Chinese history, were implemented primarily to serve agricultural production, as well as military and administrative goals. Within the same social and dynastic structure, they could not easily be tailored to meet the needs of new industries and global trade. Water management traditions, or the water planners' 'habits of thought', had for generations been concerned first and foremost with taming water, that is with drainage and defence against recurrent and dangerous floods and droughts. The relatively advanced multifunctionality of water-distribution and water-use systems in China at the time seems to have discouraged regional and local attempts at using the water primarily for transport or power needs.

Since the most developed centres of Chinese civilization in the seventeenth and eighteenth centuries were located in the Yangtze and Huang He basins, it is natural to compare the industrializing regions of Britain with these two regions or water systems. The Yangtze river was China's main trade artery, and economic progress was directly connected to the

15 Thomas Stuart Willan, *River navigation in England, 1600–1750*, London: F. Cass, 1964, p. 13.

16 Shephard Bancroft Clough and C. W. Cole, *Economic history of Europe*, Boston, MA: Heath & Co, 1946, p. 446.

17 See, for example, W. T. Jackman, *The development of modern transportation in England*, Cambridge: Cambridge University Press, 1916; Willan *River navigation*; Philip S. Bagwell, *The transport revolution from 1770*, London: Batsford, 1974.

18 See for example L. S. Yu, 'The Huang He river: a review of its development, characteristics, and future management issues', *Continental Shelf Research*, 22, 2002, pp. 389–403.

intricate network of waterways.[19] The river basin had more than 20,000 kilometres of waterways, and Marco Polo noted that thirteenth-century official reports indicated that 200,000 boats descended the river annually.[20] Transport by water was so much cheaper than by land that development in areas without water transport was usually far lower. The difference between the two modes of transport was so pronounced that it has been seen as ‘a case of premodern economic dualism’.[21] The many canals made by humans gave the region one of its most characteristic features.

However, the Yangtze plain was exceptional and the regional water transport network was incredible dense. Even so, it was not able to carry efficiently those heavy materials that fuelled the Industrial Revolution in England. Iron and coal were mostly found outside the river basin, or upstream of the Three Gorges, and were thus placed outside the existing water transport network. The transport network also had clear limitations regarding regional transport of regional goods. First, the layout of the canal system had not been established in order to serve the exchange of goods between cities and the world but mostly for drainage, the canals acting as conduits for excess water. Moreover, the water level in canals fluctuated with seasonal variations in rainfall and river discharges, and the transport canals were often not designed to move goods as efficient as possible all year round, but to move tribute at certain times of the year. Second, there were huge variations in the rivers’ water levels, with dangerous floods during some parts of the year and low waters at other times. The silting up of rivers and harbours, and meandering tributaries on the plains, made these waterways difficult to use for the transport of heavy raw materials and industrial products. The boatmen and traders in eighteenth-century England complained about the irregularity of the Severn and the Avon but, compared to Chinese rivers, they were more like faithful highways. At some places along the Yangtze, the difference between high and low water could be 60 metres, and in mountainous Chongqing it averaged 30 metres.

As for the Huang He (the Yellow River, ‘mother of Chinese civilization’), flooding transformed it into a raging torrent, carrying 88 times more water than in the dry season. The river had four natural flood seasons, which made regular and large-scale river transport extremely difficult. A detailed reconstruction of the behaviour of the Huang He from 1650 to 1850 remains to be established, but it has been concluded that from 602 BCE to 1949 CE there were more than 1,500 major floods, 25 significant channel alterations, and 7 big course changes. Like other mighty Chinese rivers, it originates high in the Himalayan range, subsequently crossing expansive alluvial floodplains, and a massive transport of sediment contributed to the shifting of its channel. The mouth thus moved from north to south and back, the most recent ‘natural’ shift occurring in 1855, when the channel mouth moved from the north side of the Shandong peninsula to the south.[22]

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19 Mark Elvin, ‘Market towns and waterways: the county of Shang-hai from 1480 to 1910’, in Skinner, *The city*, pp. 441–75.

20 Herold J. Wiens, ‘Riverine and coastal junks in China’s commerce’, *Economic Geography*, 31, 3, 1955, p. 248.

21 Mark Elvin, *The pattern of the Chinese past*, London: Eyre Methuen, 1973, p. 304.

22 Qiang Zhang, Chong-Yu Xu, Tao Yang, and Zhen-Chun Hao, ‘The historical developments and anthropogenic influences of the Yellow River up to the nineteenth century’, in Terje Tvedt and Richard Coopey, eds., *Rivers and societies: from the birth of agriculture to modern times*, vol. 5 of *A history of water*, series editor Terje Tvedt, London: I. B. Tauris, forthcoming 2010.

The interface between rivers and sea was also much less conducive to trade in China than in western Europe. China's flat coastal landscapes were formed by the deposition of fine river sediments and the river mouths were often choked with silt, and time and again their outlets to the sea would shift. There was a lack of tidal rivers, and river banks were frequently sandy and shifting. Access to the sea from the Yangtze was in general not a big problem, but one such big channel to the sea did not constitute a dynamic transport network among regions, like the one that could be developed in England. Although maritime trade was substantial and the Chinese had the technological capability to develop seaborne transport, the hazards of the maritime route were both natural and societal, including the problem of piracy. Beijing thus prioritized the Grand Canal and inland water routes.

Clichés about the inward-looking, conservative 'Oriental mind' or 'stagnant' Chinese civilization are highly misleading in regard to canal-building. The Chinese undertook several major projects from the third century BCE onwards, developing sluice and lock technologies, and constructing a myriad of canals, the most famous of which was the Grand Canal. This hydraulic system was more technologically sophisticated, administratively challenging, and managerially complex than ever by 1800.[23] The use of the canal was restricted, however, by silt and water levels and by its narrow size, making it unsuitable for heavy loads. Indeed, the Grand Canal complex collapsed in the nineteenth century, having silted up from the mid eighteenth century. Despite the experience of Qing engineers, the state did not have the resources to control the canal when changes in climate altered the amount of water carried by the Huang He.[24] Moreover, there was insufficient relatively silt-free water at a suitable altitude in Shandong to keep the canal functioning at all times of the year.[25]

The problem was not technological capabilities, for the Chinese had long been masters of canal-building. The real stumbling block was that the Chinese had to manage a dramatically more unruly water landscape. It is revealing in this context that Chinese water-system engineers for centuries distinguished between perennial and inundatory canals. The former had water all year round, while the latter drew water only in the wet season.[26] The water transport system in China that for generations impressed European travellers was that of an agrarian, irrigation economy, where rivers were used and canals built to move soldiers and grain for military and taxation purposes, and to bring water to the fields or away from the fields in times of flooding.

Moreover, the navigable rivers and the existing canal system were far from where the most important coal and iron deposits were placed, and the character of the water system made it almost impossible to overcome this comparative drawback. China's vast river system, characterized by river basins where water runs more or less unidirectionally from

23 Randall A. Dodgen, *Controlling the dragon: Confucian engineers and the Yellow River in late imperial China* Honolulu: University of Hawai'i Press, 2001.

24 Jane Kate Leonard, *Controlling from afar: The Daoguang emperor's management of the Grand Canal crisis, 1824–1826* Ann Arbor, MI: Center for Chinese Studies, University of Michigan, 1996.

25 Mark Elvin, personal communication.

26 The seventeenth and eighteenth centuries saw the publication of many books on water control. See, for example, Fu Zehong, *Xing Shui Jin Jian (Golden mirror of the flowing waters)* (1725); Kang Jitian, *He Qu Ji Wen (Notes on rivers and canals)* (1804); and Jin Fu, *Zhi He Fang Lue (Methods of river control)* (1689, but not published until 1767). All of these are mentioned in Colin A. Ronan, *The shorter science and civilisation in China*, vol. 5, Cambridge: Cambridge University Press, 1995, p. 230.

west to east, turned rivers into barriers to north–south trade in general and to the transport of heavy goods in particular. The huge rivers were often difficult to cross by boat because of their discharge variations and strong flow velocity, and they were also – unlike the many small rivers in England – impossible to cross on foot or with wagons, since bridges could not be built to span the enormous widths. Those features, which for hundreds of years had made the rivers quite efficient seasonal highways for the downstream transport of agricultural goods grown on different places along their banks, became a drawback when a regular, perennial, and gentle flow was necessary for the shipment of heavy goods.

In India, monsoon rains were the most important physical factor negatively affecting navigability, reliability, and opportunities for port establishment, restricting inland navigation to a seasonal activity in some areas.[27] For generations, the major Indian rivers were used and harnessed, and they encouraged the development of a very productive agricultural civilization, but they suffered from some of the same hydrological problems as Chinese rivers when used as transport highways.[28] The Sanskrit word for the Indus river, Sindhu, means ocean, but in the winter season, when melt water from the Himalayan glaciers was radically reduced, the river became a series of pools connected by narrow and shallow channels. On the Ganges, and even on parts of the Brahmaputra system, it was possible to move goods in the dry months from November to January, but in spring river branches became too shallow for even very small boats.[29] Conversely, during the monsoon, the rivers flooded and became dangerous for navigation. In spite of these navigational drawbacks, rivers played a very important role in traditional transport, because water transport was still more efficient than transport by land, which came to a standstill in many areas during the monsoon. In Bengal, for example, about 80% of trade was by river.

However, while rivers were crucial as local transport routes, they were not conducive to growth in national and international trade. One author concluded that rivers in India ‘are not considered fit for navigation’.[30] This problem can be illustrated in another way. One-sixth of the area of modern India is drought prone, and one-eighth of the area is flood prone, with floods on average rendering 33 million people homeless every year.[31] Although the number of affected people was lower at the beginning of the nineteenth century, floods and droughts could strike much harder, since there were insufficient dykes and storage facilities for flood water for use in the dry season.

Moreover, India is probably the country in the world that has most river migration and ‘disappearing’ waterways. Indeed, the mythical and famous river Saraswati can be seen as a

27 For an overview, see Sharad K Jain, Pushpendra K. Agarwal, and Vijay P. Singh, *Hydrology and water resources of India*, Dordrecht: Springer, 2007.

28 Ibid.

29 See, for example, Charles Rasmus Forrest, *A picturesque tour along the Ganges and Jumma in India consisting of twenty-four highly finished and coloured views, a map and vignettes from original drawings made on the spot*, London: R. Ackermann, 1824.

30 Radhakant Bharati, *Rivers of India*, New Delhi: National Book Trust, 2004, x. See also Henry C. Hart, *New India’s rivers*, Bombay: Orient Longmans, 1956.

31 B. G. Verghese, *Waters of hope: integrated water resource development and regional cooperation within the Himalayan–Ganga–Brahmaputra–Barak Basin*, Dhaka: Academic Publishers, 1990, pp. 8–9.

religious expression of this predicament.[32] A distinguishing feature of South Asia is the pattern of changing riverbeds, with cities left high and dry. This geomorphological behaviour is mainly caused by the fact that the Himalayan courses of these rivers are highly torturous, while on the plains, owing to heavy sediment load and strong flows at flood stage, they meander across the floodplain, shifting course frequently.[33] It is safe to say that there is no river in the Indus–Ganges plain that has not changed its course a hundred times, mostly as the result of factors beyond human control. From the earliest times, human settlement had followed the rivers, which meant that every deserted river implied a disturbance of settlements and the abandonment of villages, towns, or even great cities. These phenomena removed the water supply to an inconvenient distance, and altered places' strategic advantages and established trade routes. Larger changes of course have had proportionately larger consequences. Lines of mounds marking abandoned villages along the line of a former river are sufficiently common in the Punjab to have a name, *thes*.[34]

During the period of the first phase of the Industrial Revolution in England, India experienced a number of radical changes in waterways. The river Beas was 'captured' by the Sutlej, a tributary of the Indus, at the end of the eighteenth century, and its old bed became a dry ravine. The Brahmaputra also changed course. Until 1787 it had flowed through Mymensing, but then it started to move west, while the Teesta in turn formed the easternmost branch of the Ganges.[35] In times of flood, large changes in the courses of the rivers were especially apt to occur. The Damodar river had formerly joined the Hooghly about 50 kilometres above Calcutta, but in the great flood of 1770 it left its old channel altogether and joined the Hooghly about 50 kilometres *below* Calcutta. The consequence was a marked deterioration in the channel of the Upper Hooghly, and a silting up of the old channel. This lack of river stability was acknowledged by the British as one of the major obstacles to transport improvements when, some decades later, they tried to develop steamboat traffic on the Ganges.[36]

Not only were the water systems of China and India much less conducive to the rapid developments of water transport and facilities than in England, but canal construction on a large scale was technologically impossible at the time. This was because of the huge seasonal and annual variations in potential sources of water supply for artificial waterways, and the enormous sedimentation problem that threatened to destroy canals and embankments in a few years' time. Furthermore, the permanent need to protect land and people against floods and droughts made it dangerous to establish transportation canals, and strong conflicts of interests existed between the needs of the irrigation and transport sectors when it came to the type of water control works envisaged for different economic activities. The canals that existed in some regions of the two countries were not appropriate for the

32 Jain et al., *Hydrology*, pp. 870–913.

33 M. Abbas Khan, *Encyclopedia of Indian geography*, New Delhi: Anmol Publications, 2005, vol. 2.

34 W. A. Wood, 'Rivers and man in the Indus–Ganges alluvial plain', *Scottish Geographical Magazine*, 40, 1924, p. 3.

35 Arthur Michel, *The Indus river: a study of the effects of partition*, New Haven, CT: Yale University Press, 1967, p. 48. See also Henry T. Bernstein, *Steamboats on the Ganges: an exploration in the history of India's modernization through science and technology*, Calcutta: Orient Longman, 1960, pp. 14–16.

36 Bernstein, *Steamboats*.

transportation of goods such as coal and iron, since they had not been built with that purpose in mind. Nor were their rivers suitable as arteries for global trade, owing to their strong seasonality and the sediment problem where the rivers met the ocean. The boatbuilding technology available at the time made it nearly impossible to build boats that could carry heavy goods on such seasonal, violent rivers. Large parts of the two countries had no navigable waterways whatsoever, and in general the major rivers did not run close enough to where coal and iron were found in sufficient quantities.

Trade, the instrument of any developing economy, had for centuries been hampered by transport. It was invariably slow, inadequate, irregular, and, not least, very expensive. As Paul Valéry remarked: 'Napoleon moved no faster than Julius Caesar.' The water transport system that developed in England during the latter part of the eighteenth century signalled a transport revolution. No other country or region in the world possessed the same water system and network of waterways. Although transport was still slow, trade of heavy goods could be quite reliable. It could be carried out on a year-round basis, and boats on the small rivers and canals could carry iron, coal, and sand from where they were found to where they were to be used. Only in England could an efficient, reliable transport system be established at that time, bringing the different regions together and linking them to regional and global trade routes. By comparing the complex and multifunctional water systems of the late eighteenth century in the industrializing regions of Britain with the most developed regions of India and China, it is possible to account for fundamental variations in the scale and character of their transport networks.

Manufacturing and water systems in England

Whatever definition one takes of the Industrial Revolution, they all emphasize the centrality of the rise of the modern factory, originating in England in the last third of the eighteenth century. Even if not in itself a sufficient explanation, the use of machinery remains the principal aspect in relation to which every other issue is studied. And before the steam engine came into wide use in the mid nineteenth century, only two forms of inanimate power were available – wind and water.[37]

As windmills were too unreliable for new production processes, water power made large mechanical workshops feasible, fostering industrial discipline among a modern working class. Water was the main power source in the initial phase of the Industrial Revolution. All important industries, such as textiles, iron, paper, and pottery, and a myriad of less important ones were driven by or dependent upon water power of this type. A number of writers have shown that water power continued to be the most important source of industrial energy well into the nineteenth century.[38] It is therefore crucial to understand and analyse in a comparative perspective the role of water power, notably the reasons for its dominance in England and for its marginality in China, India, and other European countries

37 Martin Watts, *Water and wind power*, Aylesbury: Shire Publications, 2005, p. 53.

38 G. N. Von Tunzelmann, *Steam power and British industrialization to 1860*, Oxford: Clarendon Press, 1978; N. J. G. Pounds, *An historical geography of Europe 450 B.C.–A.D. 1330*, Cambridge: Cambridge University Press, 1973, p. 38; and John William Kanefsky, 'The diffusion of power technology in British industry, 1760–1870', PhD thesis, University of Exeter, 1979.

at that time. While this article deals with the role of water systems in the Industrial Revolution as a whole, the discussion now focuses on the water-powered mechanization of the textile industry because of this industry's particular centrality in analyses and discussions of why England succeeded and India and China did not.

While water remained the main and only reliable source of inanimate power, the water wheel was the key technological factor in all the basic and new industrial processes. While it had existed for roughly 2,000 years, it was the first phase of the Industrial Revolution that saw the zenith of the societal and economic importance of the water wheel, which most new factories employed to drive their machines. For the more efficient, vertical water wheels that had been developed, the overshot wheel almost always required an aqueduct, often elevated, leading water to the very top of the wheel, where it poured into the buckets, the weight of water causing the wheel's rotation. The necessary aqueducts could be artificially made by constructing small dams and millraces.

The water system needed to satisfy three demands: a year-round supply, not too much silt, and adequate stream power, able to turn the wheel 24 hours a day throughout the year. This particular relationship between economic activity and natural resources meant that the new factories had to be located where there was running and falling water. Thus, the fundamental comparative question becomes that of where one could find water that could easily be adapted to the need of the new industries, and that was also located close enough both to sources of raw materials and to national and global trading routes. In spite of the importance of this form of inanimate power in the first phase of the Industrial Revolution, no systematic comparison of water systems located in this historical context has been undertaken.

Parts of England, as well as Wales and Scotland, had water systems conducive to this type of industrial power. The great number of relatively small perennial rivers, such as the Derwent, Irwell, and tributaries of the Severn, with modest year-round currents and silt-free water, were perfect for existing water-wheel technology and for testing new developments.[39] The conditions that prevailed in different areas of England had, for centuries, made it an ideal workshop for practical engineering and experiments, which encouraged a great variety of water-related inventions. This disparate economic-technological milieu grew in size and importance, and in the last decades of the eighteenth century it turned out a number of new inventions, such as the water frame, Crompton's mule, and Henry Cort's grooved rolling process and pudding furnace. It was comparatively easy to execute projects for channelling sufficient water to where the water wheel was situated, owing to varied experiences with minor modifications of river embankments and canal construction, and the existence of a decentralized, bottom-up water management system. But why did the water-powered mechanization and technology flourish much more richly in Britain in the period 1760–1820 than in what might be called its European birthplaces – parts of northern Italy and eastern France? To explain this fact, many factors must be considered, but one main reason was the great discharge variations of the Alpine rivers: the force of the peak currents and the turbulent, flood-prone rivers such as the Rhone and the Po made it difficult to establish modern year-round factories and to market their produce worldwide.

39 Edward Baines, *The history of the cotton manufacture in Great Britain*, London: Fisher, Fisher & Jackson, 1835, pp. 55–83; Robert Robson, *The cotton industry in Britain*, London: Macmillan, 1957, p. 1.

The textile industry was the leading sector in the Industrial Revolution and the first to take on new forms of industrial organization. The most spectacular growth occurred in the cotton industry between 1750 and 1800, by which date Britain had become the leading exporter of cotton cloth.[40] This power shift was made possible by many factors, political, cultural, and imperial, but without the development of new factory technology (such as new spinning and weaving machinery in England) it would not have been possible. When multiple spindles began to be mounted on frames it became evident that human power was inadequate, and as long as water power was the only available substitute for human and animal energy, the water system attained a new and fundamental social and economic importance. Indeed, yarn made this way was known as 'water-spun' as opposed to 'hand-spun'. Cotton could not be grown in England, for climatic and irrigational reasons, but it could be manufactured there, because of those same features of the climate and water systems.

It is therefore symbolic that the location of the first modern factory in history – a cotton mill in Cromford near Derby, established in 1771 – was on a river, on the banks of the Bonsall Brook, a tributary of the River Derwent. Arkwright's 'water frame' was installed here to be powered by large water wheels. The mill swiftly grew to house several thousand spindles and 300 workers. A disadvantage of the Cromford site was poor communications, so Arkwright had the Cromford Canal built to transport raw materials and finished goods to and from the site. In 1780, the owner bought land for another, bigger factory complex and a larger mill, and moved to a more powerful river, the Derwent itself. Fifteen years later, there were 140 similar water-powered mills spinning cotton. By 1800, there were about 900 cotton-spinning factories, most of them in the North and the Midlands, of which 300 had more than fifty workers. In the late eighteenth century, there were nearly 100 cotton mills within a ten-mile radius of Ashton-under-Lyne, all on the River Tame and all powered by water. By 1816, the average number of workers employed in forty-two Manchester textile factories was already as high as 300.[41] More efficient technologies were developed that increased productivity and quality; Crompton's mule gradually overtook Arkwright's water frame as the preferred machinery, but this was also set in motion by water wheels, fitted with as many as three or four hundred spindles. In 1835, there were 109,626 power looms in use in the cotton industry in the United Kingdom.[42] The cotton mill became a definitive symbol of the Industrial Revolution, signifying material progress and a growth of industrial spirit and identity. Mechanization of wool spinning and weaving took place during the same period, using water at crucial stages in the production process. The mill and all that came with it thus marked the dawn of a new era. It was not until 1783 that the steam engine was first used in a factory, albeit indirectly (Arkwright's Manchester mill used a Newcomen engine to

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40 Thomas Ellison, *The cotton trade of Great Britain*, New York: A. M. Kelley, 1968, pp. 57–70; Robson, *Cotton Industry*, pp. 1–3.

41 Arthur Redford, *The economic history of England, 1760–1860*, Westport, CT: Greenwood Press, 1960, pp. 19, 27.

42 Chris Aspin, *The water-spinners: a new look at the cotton trade*, Helmshore, Lancs.: Helmshore Local History Society, 2003. See also Baines, *Cotton Manufacture*; Witt Bowden, *Industrial society in England towards the end of the eighteenth century*, New York: Macmillan, 1925; William Daniell and Richard Ayton, *A voyage round Great Britain*, London: Longman, 1814; and R. L. Hills, *Power in the Industrial Revolution*, Manchester: Manchester University Press, 1970.

pump water to drive the machines in the dry season, when the water pressure was insufficient to turn the water wheel).

At the beginning of the nineteenth century, in brooks and streams all over England, water wheels were established, effectively powering not only the textile industry but also the metallurgical industry. Indeed, steam engines could not have been built in the first place without water wheels to drive the machinery that was needed to smelt the iron and form the cylinders that the steam engine was made of. The development of the iron industry was crucial because it allowed the production of most of the machine equipment required by other industrial activities, whereas earlier machines were made of wood. The key factor in the iron industry was the heating process and the hammering of smelted iron, both of which depended wholly upon water power. Without water-powered bellows, it would simply not have been possible to produce temperatures in the blast furnaces high enough to produce cast iron economically. This water-aided furnace technology was an essential element of the iron industry and its high output. The iron industry depended on water power to produce the new machines of the new industries, such as rolling mills, metal lathes, and hydraulic hammers, which again required water power. It is therefore safe to assert that the increase in productivity was dependent upon more efficient use of water, in this industrial sector as in other emerging industrial sectors at the time.

The success of water-wheel technology in England cannot be sufficiently explained by European politico-ideological exceptionalism, or by European colonialism and unfair global trade regimes. The fundamental technology itself was not a European invention but was first developed in Asia, most probably in India or China. It was introduced to England by the Roman conquerors. From the very beginning, however, the technology spread quickly in England. At the time of the Doomsday Book, compiled for William I in 1086, more than six thousand water mills were registered, using the large number of small brooks and streams full of water at the time of year when the corn was harvested. The water wheel was then primarily used for grain milling but was gradually taken on for other purposes. The mechanical fulling mills that cleaned woollen textiles were especially important. Around 1200, water-powered hammers were put to use at a number of small rural forges for beating hot ore bodies into different shapes. The Wealden iron industry was located close to streams because it was possible to accumulate the heads of water needed to drive the hammers there. Great improvements in water-mill technology took place in the sixteenth and seventeenth centuries.[43] However, the development of the overshot system was crucial for the industrial breakthrough.[44] Technologically, the equipment in itself was not revolutionary, and it would probably not have puzzled or surprised a millwright from medieval China or parts of the Ottoman Empire. Many of the early water-powered cotton factories were converted silk mills, which themselves were often converted medieval corn mills, pointing to the long and varied history of water-powered technologies.[45]

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43 George Unwin, Arthur Hulme, and George Taylor, *Samuel Oldknow and the Arkwrights: the Industrial Revolution at Stockport and Marple*, Manchester: Manchester University Press, 1924, p. 27.

44 Terry S. Reynolds, *Stronger than a hundred men: a history of the vertical water wheel*, Baltimore, MD: Johns Hopkins University Press, 1983.

45 Samuel Lewis, *A topographical dictionary of England*, 7th edition, London: S. Lewis and Co., 1848, vol. 1, p. 95.

At the end of the eighteenth century, entrepreneurs and business people in parts of England had broad experience with the use of water wheels for productive purposes, the water system having created possibilities for industrial expansion and technological innovation for centuries. The role of and dependence on water can also explain the distinct regional patterns of England's transformation in the late eighteenth century, because industries (which were often clustered in combinations of textiles, iron, and engineering) had to congregate along streams and brooks. Conversely, no similar transformations took place in parts of England that lacked rivers and brooks with sufficient force to power water wheels, or where it was not possible to build dams, reservoirs, and manmade waterfalls that could drive these 'water engines'. For example, it mattered that about 250 kilometres of year-round, ice-free, and stable rivers, streams, and manmade canals flowed through Manchester within 15 kilometres of the city centre. Some waterways, such as the Dene, Tib, and Corn Brook, important in previous centuries, have now been forced underground, while four rivers still flow visibly through the city: the Irk, Irwell, Medlock, and Mersey. It also mattered that the water ran down gentle hills, thus carrying sufficient clean energy to drive the water wheels. After all, the Romans called this area Mamucium, the place of the breast-shaped hill (from which the word Manchester later derived) because of the contours of the landscape.

Water-powered mechanization in the core economic regions of China

Explanations of England's triumph based on assumptions about European technological supremacy are not very convincing when it comes to water control, for water power had already been an important source of energy in ancient Chinese civilization. In fact, China led the West. Large rotary mills for grinding grain appeared in China in about the second century BCE. The typical Chinese water wheels were of the horizontal type, although the vertical wheel was known, and was used to operate trip hammers for hulling rice and crushing ore. The edge-runner mill appeared in China in the fifth century CE. The trip hammer was in use perhaps as early as eight centuries before it was used in Europe, and China invented the first water-powered blast furnace, although most eighteenth-century furnaces still depended on manually powered bellows. China had factory-like establishments, and iron works that employed in the region of a thousand men.[46] Some historians argue that iron output in the eighteenth century was greater than ever, possibly exceeding 200,000 tons per year.[47] Moreover, the Chinese were certainly acquainted with milling technology, as the earliest paper mills date from around 1570, the earliest sawmills from 1627, and mills for winding silk from cocoons from 1708.[48]

46 Elvin, *Pattern*, pp. 307–8. See also Donald B. Wagner, 'Some traditional Chinese iron production techniques practiced in the 20th century', *Journal of the Historical Metallurgy Society*, 18, 2, 1984, pp. 95–104.

47 Lloyd E. Eastman, *Family, fields, and ancestors: constancy and change in China's social and economic history, 1550–1849*, Oxford: Oxford University Press, 1988, pp. 137–47.

48 Joseph Needham, *Science and Civilization in China*, New York: Cambridge University Press, 1996, pp. 4, 404, 394, 405.

It has been documented that a water-powered multi-spindled spinning machine was in use in northern China by the end of the thirteenth century.[49] We do not know why this early Chinese machine-spinning disappeared, but a reasonable hypothesis is that it was related to local and perhaps dramatic changes in the water system, and to a general shortage of suitable rivers for this type of industrial activity. What we do know is that water continued to be used as a power source in various places where it was available, since the Chinese were well aware of the labour-saving benefits of using water power to turn machines. In Hunan, water was lifted with stream-turned norias, and a contemporary poem praised how much easier this was than pedalling.[50]

Since they knew the technology, the Chinese had the scientific and engineering capability to build reservoirs and dams, but they could not sufficiently regulate the extremely variable flow on a year-round basis, which this new kind of industrial production required to be profitable. Furthermore, the reservoirs soon filled with silt. The Chinese water system was extremely difficult to use for regular industrial production given available technology at the time, and therefore Chinese factories lacked a regular power supply that could transform them into modern machinery-based workhouses. There were very few exploitable water resources close to where iron was found and made, and the rate of invention and application was much slower than in western Europe and England.[51]

The question of the Chinese cotton textile industry has been thoroughly discussed. The Chinese had the technological capacity, enough raw cotton, and sufficient demand for cotton textiles to develop modern cotton-textile factories, but no such factories were established before the latter part of the nineteenth century when the steam engine was introduced. China's textile industry was overwhelmingly located in the populous Lower Yangtze region, for long the core of the Chinese economy, where big merchants established considerable control over the production process of higher grades of cloth.[52] The Ming cotton industry demonstrates that the idea of the stagnant Chinese society is misplaced, since a family-based rural weaving and spinning industry, employing hundreds of thousands of people, had developed in the eighteenth century, stimulating important changes in production and marketing. Lindsey, in his account of the visit of Lord Amherst in 1816, wrote that the spinning and weaving was carried out by every family in the many small villages dotting the area around Shanghai.[53] Although the Chinese knew the technology of water mills, and

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49 Elvin, *Pattern*, p. 286. Elvin also notes examples in Guangdong, Jiangxi, and Fujian during Qing times of making incense and paper, and husking rice.

50 Mark Elvin, 'Unseen lives: the emotions of everyday existence mirrored in Chinese popular poetry of the mid-seventeenth to the mid-nineteenth century', in Roger T. Ames, Thomas P. Kasulis, and Wimal Dissanayake, eds., *Self as image in Asian theory and practice*, Albany, NY: State University of New York Press, 1998, pp. 113–200, 136–7.

51 Mark Elvin, 'The high-level equilibrium trap: the causes of the decline of invention in the traditional Chinese textile industries', in W. E. Willmott, ed., *Economic organization in Chinese society*, Stanford, CA: Stanford University Press, 1972, pp. 137–72.

52 Sadao Nishijima, 'The formation of the early Chinese cotton industry', in Linda Grove and Christian Daniels, eds., *State and society in China: Japanese perspectives on Ming-Qing social and economic history*, Tokyo: University of Tokyo Press, 1984, pp. 17–79.

53 Hugh Hamilton Lindsay and Karl Friedrich August Gützlaff, *Report of proceedings on a voyage to the northern ports of China, in the ship Lord Amherst: extracted from papers, printed by order of the House of Commons, relating to the trade with China*, 2nd edition, London: B. Fellows, 1833, p. 188.

acknowledged its advantages, they still did not use it in cotton-producing regions. Eastman argues that 'A critical weakness of the industry, however, was the relative absence of mechanization.' Since the Chinese knew how to harness water power, the explanation for this weakness 'probably resulted from a rational economic decision'.[54]

However, the Chinese were also unable to copy English textile machinery, even if all other factors had been equal, because they did not have the rivers, streams, and brooks that could power the new industry. The river-control works of the past were engineered to solve other tasks, and served water interests and water works that would compete with projects taming the river for harvesting its industrial powers. China's river landscape and water system made it difficult to develop an extensive system of water-powered industry. On the extremely flat Yangtze plain, crossed by a violent, silt-laden river, draining 70–80% of China's precipitation, there were very few appropriate places to exploit the flow of water for driving water wheels, especially overshot vertical wheels. The Yangtze and its main tributaries could not be used for producing power through numerous water wheels, in the way that the much smaller and more modest English rivers, streams, and brooks could. In major cotton-producing regions, there was simply not sufficient head of water to work hydraulic machinery. Successive floods also functioned as major disturbances influencing the dynamics of the river–land interface, and human–water relations made factory establishment on the river banks virtually impossible. The Huang He could not be used either, not only because of its irregularity and the fact that it broke through the levees almost every year, causing floods and displacement, but because of the amount of silt transported by the river, which could easily damage or destroy the vulnerable water wheels.

Dominant explanations have focussed only on different types of social variable, thus overlooking a fundamental geographical constraint in China: the physical lack of relevant inanimate power sources for machinery. To explain the lack of suitable water channels and waterfalls as a function of a lack of entrepreneurship, capital, or competence, is highly misleading. Thus, Kang Chao's seminal book points to a number of factors that can help to explain what he calls a great puzzle, but he does not bring the difficult water system into his narrative.[55]

Water-powered mechanization in the core economic regions of India

Until the latter part of the eighteenth century, India was the main cotton-textile producer in the world.[56] According to some estimates, it accounted for 25% of the world's manufactures in 1750.[57] The key to this production process was the pit loom, a technology that

54 Eastman, *Family*, pp. 146–7.

55 Kang Chao, *The development of cotton textile production in China*, Cambridge, MA: Harvard University Press, 1977.

56 Prasannan Parthasarathi, *The transition to a colonial economy: weavers, merchants and kings in south India, 1720–1800*, Cambridge: Cambridge University Press, 2001.

57 Paul Bairoch, 'International industrialization levels from 1750 to 1980', *Journal of European Economic History*, 11, 1982, p. 296.

endeavoured to mechanize work previously achieved entirely through human labour. The horizontal loom was lightweight, consisting of only a few pieces of wood tied together, which could easily be disassembled, transported, and reassembled. In the late eighteenth century it was not uncommon to see an individual weaver moving from dwelling to dwelling, carrying on his back everything necessary to start weaving the moment he arrived at his new home. The pit loom's mobility was an advantage for weavers since they could compete with other weavers locally. However, technologically it was at a disadvantage compared to the efficient factory system established in England. This loom was, however, also totally dependent upon water, but in entirely different ways and with far-reaching implications. The hole under the loom where the weaver sat and worked the pedals, hence the name 'pit loom', created the proper humidity for the cotton to be woven. In parts of south India, however, even hand-weaving itself came to a standstill for about a month because of the heavy rains. In some areas, severe winds were a regular, yearly problem, breaking up 'the warp yarns that were fixed in the loom'. In Kongunad, such a work schedule was reflected in concentrating festivals for the left-handed caste, of which weavers were an integral part, in the months of the monsoon. During the rains, the yarn preparation, which was done outdoors, could not be performed.[58]

Before the steam engine liberated industries from the river banks, India did not possess the necessary power sources to develop a modern factory system, because of the difficulty of exploiting rivers in both the rainy and the dry seasons.[59] Moreover, the large rivers crossing the northern plains had very few places with a sufficient head of water. The elevation of the Ganges, for example, drops only 700 feet on its thousand-mile journey from Delhi to the sea. The extreme monsoon pattern in India brings 90% of the yearly rainfall between June and September, resulting in swollen, violent rivers. During the remainder of the year, rivers were shallow, slow-running, and some even dried up entirely. To use these rivers for year-round power production was nearly impossible at the time. They also ran through flat plains, whose only relief were flood-plain bluffs and belts of ravines and badlands formed by gully erosion along the larger streams. The steady or sudden migration of rivers and river beds made factory-building on river banks a highly risky business. In Bengal, where the textile industry was strongest, rivers meandered through the slopeless plain of the Ganges–Brahmaputra delta. About 80% of present-day Bangladesh is less than ten metres above sea level, and in the flood season almost half the country is normally under water. The rivers in the southern parts of the subcontinent depended almost completely on the monsoon and were in general more irregular than the Himalayan rivers.

In India in general, therefore, inanimate power was only used in a few places where water mills could be established. There were water mills along some of the streams of the Deccan plateau, where Pan Chakki took its name from a seventeenth-century water mill that used to grind grain for the pilgrims and troops of the garrison. A mountain spring provided the water that powered the mill. Water power was also used in the north-western district of Hazara 'to manoeuvre a wooden trip-hammer for milling rice'. The vertical wheel was also found in a water-driven cotton gin in another part of the same district. The latter, it has

58 Parthasarathi, *The transition*, pp. 12, 19.

59 For a description of technology in the iron industry in the eighteenth century, see Dharampal, *Indian science and technology in the eighteenth century*, Goa: Other India Press, 1971.

been argued, was a local invention.[60] Hazara had, in contrast to the rivers on the plains and in the Deccan, water that could drive a mill, to a large extent on a perennial, year-round basis. These few pockets of water-powered technology underline that the technology was known, and they indicate that the problem was the diffusion of this technology to the very different water systems dominating the central economic regions of India.

Conclusion

This article has shown that an inclusive explanation of why the West developed and not the rest of the world, and why certain regions of England were first to industrialize, must consider and analyse the complex, multifunctional water systems in which these developments took place. The reason is that, before the dominance of the steam engine, the transport revolution, the development of the modern factory system, and the growth of the iron and other industries that transformed parts of England from the 1760s to the 1820s were all related to changes in the human relationship to water. This article has shown that the central economic and political regions of India and China did not have water systems that could be used or developed as easily and profitable as they could be in parts of England. On the contrary, it is argued that these countries' water systems prevented, or at least obstructed, similar transformation processes at the time.

Water systems affected other important variables relevant to growth and development that have not been covered in this article. In particular, it has not specifically dealt with the third layer of the water system, management practices and ideas about water. In the latter half of the eighteenth century, Chinese water management traditions could be categorized into four main activities: drainage, flood control, irrigation, and transport. Drainage had been a main activity on the flood plains, owing to the combined impact of the monsoon, melting ice in the Himalayas, and the flatness of the land. Even the creation of the world was connected to mythical stories about drainage: Emperor Yu became mythical because he managed to drain the lowlands. Flood control had been a key task throughout Chinese history and especially on the lower courses of the big rivers. Navigation canals were therefore in some cases a sort of fringe benefit of proper levee maintenance. The establishment through the ages of a system of drainage canals, and the water management system established to oversee their maintenance, was more a hindrance than a benefit to building canals for the efficient transport of goods and for turning the rivers into power sources for new machines. The density of irrigation canals, in both the Yellow River and the Yangtze basins, also hindered water transport development and the use of water for power production, because these needs collided. During the Ming and Qing dynasties, the Director General of Waterways was responsible for management of the Grand Canal and the lower Yellow River basin, and his main task was to prevent damage to the Grand Canal. This very powerful state agency has been described as no more than an adjunct of the Grain Transport Administration, and therefore not interested in building canals for transport of other goods

60 Tapan Raychaudhuri, 'Non-agricultural production: Mughal India', in Tapan Raychaudhuri and Irfan Habib, eds., *The Cambridge Economic History of India, volume 1: c.1200–c.1750*, Cambridge: Cambridge University Press, 1982, pp. 292–3.

from other places, or with building dams and ponds for mechanical water-power production, not the least since such projects would have made management of the Grand Canal even more complicated and difficult.

In England, management traditions and ideas about how water should be used were much more pluralistic and the state or the economic elite had no specific or strong vested interests in a particular type of water management. There were, of course, conflicts between different water usages in England, too, but since irrigation and irrigation canals were of marginal importance, the conflicts arose more within the modernizing sectors of the economy: between those who wanted to develop the waterways for transport and those who wanted to develop them for power production. Since the water landscape was so diverse and the rivers had been of marginal economic and political importance for other sectors of society, water entrepreneurs could emerge and operate quite unhindered by state intervention and mostly supported by that same state.

The issue of cultural constructions of water can also be mentioned briefly. The transformation of the rivers into a form of natural capital and as a means of producing profits for individual entrepreneurs, as happened in England, did not occur in India. The cultural construction of water or water resources there was not concerned with how to put them to work in the production of a new social and economic order. On the contrary, water had been recognized as a primordial spiritual symbol since Vedic times,[61] and the seven big rivers, especially the Ganges, were the pivot of regional sacred geography; hence, all over the country there were temples, holy tanks, and important places of ritual on riverbeds.

The climatic history of these countries in the eighteenth century must also be studied in greater detail. For example, it has been established that, during those very same decades that England prospered, terrible floods and droughts devastated parts of both India and China.[62] These rapid and partly uncontrollable changes in the water systems obviously contributed to dynastic decline, but no research has as yet been published on how this affected these countries' economic development as compared to England's during these decades. In addition, water systems also fundamentally affected health, living standards, population growth, and therefore labour productivity and labour costs. In India, for example, malaria was rampant and has been called 'Killer no. 1' in the subcontinent. To date, nobody has presented a systematic comparative study of the consequences of waterborne diseases on global and national productivity levels in the eighteenth century.

Finally, it needs to be recalled that the water system of England eventually proved to be an obstacle and a barrier as development continued during the nineteenth century, in terms of both transport and power. Comparative studies of the shift from water power to steam engines, and from waterways to railways, can provide new insights into the Industrial Revolution and debates as to the origins of the modern world.

With a focus on the period from the 1760s to the 1820s, this article opens up a research project on the Industrial Revolution that locates it within a deeper history of technological change, water landscapes, and water control. There is general agreement among scholars

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61 Frans Bartmanns, *Apah, the sacred waters: an analysis of a primordial symbol in Hindu myths*, Dehli: B.R. Publishing, 1990.

62 These issues will be addressed in my forthcoming book, tentatively entitled *Why China and India failed and Europe succeeded: a new interpretation of the Industrial Revolution*.

that the character of the water system made it possible for the first riverine irrigation civilizations to develop in Asia and in the Middle East about 5,000 years ago. The erratic character of the rainfall and the rivers' intense seasonality and silt load were transformed into an advantage by human intervention. Large and prosperous agricultural civilizations were established with the help of artificial watering. From the Indus to the Yellow River, great civilizations rose from the life-giving waters of these turbid, violent river systems and, especially in China, there emerged a strong water management tradition, geared towards control and defence. This article has suggested that the very conditions that gave Asian irrigation economies a comparative advantage for millennia became a disadvantage by the eighteenth century. The same water system that was conducive to agriculture made it extremely difficult to establish modern factories based on water power along English lines, and stifled the establishment of an efficient system of year-round waterways for transport.

Many factors must be considered in explaining why parts of north-western Europe were at a disadvantage compared to Asian irrigation civilizations during the long historical period when agriculture dominated, but one of the most crucial is that rain-fed agriculture was far from being as productive as agriculture based on artificial watering and fertile, silt-laden soils, and that the long, snowy winters reduced the cropping period and the possibility for multiple harvests. This part of the world did also develop a water management bureaucracy, but it was much smaller and less powerful. Moreover, its habits of thought were geared not towards river control and flood defence but toward mills and locks, and had been so for centuries. In the later eighteenth century, during the first phase of the Industrial Revolution, those hydrological conditions – which had worked against radical productivity gains in the early phase of the agricultural age – gave this part of Europe a decisive advantage over Asia. The water landscape of parts of England, and to a lesser extent of parts of western Europe, was relatively easy to exploit, control, and develop, both as transport routes and as sources of power, because of an abundance of medium-sized, perennial rivers and brooks, which could be exploited all year round, twenty-four hours a day. The rapid economic development of the latter part of the eighteenth century had been in the making for generations, as thousands upon thousands of millers, engineers, and boatmen had experimented with and improved technologies and machinery, exploiting countless small, silt-free, benign brooks and year-round streams in this part of Europe. By including both social and natural factors in the narrative, this non-reductionist analysis of the Industrial Revolution makes it possible to explain its gradual as well as regional character of development. It becomes possible to distinguish between necessary and sufficient causes and between causes and preconditions. Explanations that argue that only European exploitation and unequal trade relations, or cultural ideas and traditions, can explain the 'great divide' cannot be sustained.

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