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Technology in Colonial India: Three Discourses

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Tirthankar Roy

Abstract

The historiography of the development and diffusion of technology in the modern world has grown as a collection of discourses, which differ in points of emphasis. The three common points of emphasis are state intervention, cultural makeup of societies, and economic calculations. The disjointedness characterizes the literature on colonial India (1857-1947) as well, complicated further by the need to understand the role that British colonial rule played in these processes. The present survey discusses, compares, and evaluates the diverse narratives.

For many economic historians, the significance of the nineteenth century lies in paradigm shifts in scientific knowledge and industrial technology in northwest Europe. By means of trade, migration, investment, and colonialism, the new knowledge came in contact with science and technology in the non-western world. A large scholarship has studied the interaction. The literature on India is especially rich, thanks in part to the archives left behind by the British Empire in India. The aim of the essay is to review the different readings of how the East-West interaction proceeded.

The scholarship has developed as three separate discourses. One of these places the empire at the centre. The empire, in this view, was the major channel of transmission of western knowledge into India, but also shaped the transmission process in particular ways

[1] I wish to thank Simona Valeriani, who read an earlier version of the paper and offered very helpful comments and suggestions.

that reflected and possibly reinforced India's dependent status. A second set of writings discuss entrepreneurial choices with reference to expected profits and opportunity costs associated with the choice of techniques. A third strand places the cultural aspects of Indo-European knowledge-exchange at the centre, recognizing that the diffusion of knowledge cannot be separated from the manner in which Europeans and Indians came in contact, modes of communication between them, their relationships of trust and power, and the role of intermediaries in cross-cultural negotiations. The crafts appear in the first of the three discourses as an obsolete tradition, and in the second as a creative agent of industrialization. They are absent from the third.

Although all three are interested in the diffusion of knowledge, these branches do not share a single root. They adopt different approaches and often use different examples. In part, the disjointedness stems from the nature of the field. The history of technology in other regions of the world, even that of the British Industrial Revolution itself, has developed as a collection of theories. In colonial India, the disjointedness has a particular source: interpretations of the significance of the empire. The diversity calls for an explicitly comparative survey, a task that has not yet been attempted in the discussion on science and technology in colonial India.

The remaining part of the essay will discuss the major contributions dealing with the three themes – empire, profit, and culture. The essay concludes with a comparative assessment of the three approaches.

Empire

The thesis of the empire narrative is that British colonialism enabled the transfer of newly developed technological systems from Britain to India, but the process of diffusion of

knowledge in India was mediated by colonial priorities, in such a way that transfer of technology did not build capability.

Imperial rule led to the transfer of many western technologies into Asia and Africa. But, like a child receiving a complicated toy, the Asians and the Africans remained bereft of the knowledge of how these were made. Their colonial masters did not teach them to "understand, and not just desire, the alien machinery".[2] A biased and westernized system of education designed to create loyalties rather than capabilities added to the syndrome. Further, the empire encouraged those knowledge packages that were "useful to the imperialists" either in the business of governance or in helping expatriate capital.[3] Modern industrialization, in this view, became possible only in the interwar period when the imperial government shed its indifference out of political self-interest, a positive turn enabled by "the slightly loosened hold of imperialism" upon the Indian economy.[4]

This view on technology parallels that on the diffusion of scientific ideas, which, again, has been seen mainly as "a purveyor of solutions to the needs of imperial governments".[5] Western science had political authority to back it up, and a political purpose to serve. "Science, modernization and domination all marched together."[6] The result was at best indifference towards, and at worst a deliberate obliteration of indigenous science, as colonialism institutionalized science teaching.[7] The pessimistic reading of the Empire as an obstruction also resonates well with postwar theories of late industrialization, starting with

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[2] Daniel Headrick, *Tentacles of Progress*, 16.
[3] Daniel Headrick, *The Tools of Empire*, 10, 205; Zaheer Baber, *The Science of Empire*; Ian Inkster, "Colonial and Neo-Colonial Transfers", and Inkster, "Science, Technology and Imperialism".
[4] I borrow the expression from A.K. Bagchi, *Political Economy*, 36.
[5] Roy MacLeod, "Nature and Empire".
[6] Deepak Kumar, "Science and Society"; Ashis Nandy, *Science, Hegemony and Violence*. With science in context, the relationship between colonialism and modernity is explored in Gyan Prakash, *Another Reason*.
[7] See, for example, Deepak Kumar, *Science and the Raj*; and S. Irfan Habib and Dhruv Raina, eds., *Social History of Science.*

Alexander Gerscenkron, almost all of which have made a fetish of the activist and developmental state. The British Empire as a state fell far short of this ideal.

Research conducted within this paradigm has paid particular attention to administrative practices. In the field of technology, two examples seem to support these ideas, these are, the railways and iron and steel. India was the site for construction of an extensive railway system. The connection with Britain through trade, investment, and colonialism was crucial in the decision to build the railways and the manner in which the railways were built. A buy-British bias in procuring rolling stock and locomotives, and the engagement of British companies under profit guarantee, it is believed, weakened the potential spillover effects of the railways. The railways did not stimulate, not at least until 1914, the development of an indigenous metallurgical and engineering industry. Being funded partly out of capital raised in London, and partly the taxpayer's money, its effects upon domestic financial market was weak too.

In the empire story, the artisan enters as the representative of a dying indigenous tradition involving loss of knowledge. In iron and steel, as well as in the more well-known case of cotton textiles, a large indigenous artisanal industry died out due to cheap import of iron manufactures and cotton yarn and cloth from Britain.[8] From the eighteenth century, iron was one of the principal imports of India from Britain, and at the end of the nineteenth century, two commodities, manufactured iron and cotton textiles dominated the import basket. The decimation of the crafts signalled a loss of knowledge. A modern (machine-using and factory-based) industry in textiles and steel did develop, but was beleaguered by indifference and hostility of the colonial state towards enterprises owned by Indians.[9]

[8] A.K. Bagchi, "De-industrialisation in Gangetic Bihar"; and Bagchi, "De-industrialization in India".

[9] S. Bhattacharya, "Iron Smelters"; A.K. Biswas, "Iron and Steel"; Tirthankar Roy, "Did Globalization Aid Industrial Development"; R.S. Rungta, *The Rise of Business*

The pessimistic reading of technology does not explain well why the tropical world's most impressive and offbeat modern industrialization happened in India, a region not only ruled by an imperial state indifferent about domestic development, but also one where agriculture produced little surplus and where capital was expensive. In the presence of so many obstacles, including the political one, textbook theories of late industrialization should predict that colonial India would not industrialize at all, and yet it did. By any benchmark, the growth rate of manufacturing between 1870 and 1940 was impressive. Factory employment increased from near-zero to two million, accompanied by sophisticated urban services including commerce, banking, education, and transportation. No other region in the poor tropics industrialized on a similar scale as did India. But even though impressive and offbeat, the industrialization was concentrated in the three port cities, Bombay, Madras, and Calcutta, and in two textile industries, cotton and jute. Whatever factor worked to overcome the obstacles were concentrated in space. What were these factors?

The suggestion that this industrial drive happened without real understanding of how technology worked misses the point. Knowing how machines worked need not always matter to their productive use. The Bombay mill-owners did desire to possess textile machinery, and they did not necessarily understand how the spinning machine actually worked. In fact, their preference for keeping a deliberate distance from technological decisions was well-known. But their real contribution lay elsewhere. Money was scarce in India, and even in the port cities, the interest rates for the safest loans tended to be two or three times that in London or Amsterdam. The mill-owners solved the problem of pooling large amounts of capital for investment in unknown and risky ventures.

Corporations"; Headrick, *The Tentacles of Progress*; A.K. Bagchi, *Private Investment*; R.K. Ray, *Industrialization in India*; M.D. Morris "Growth of Large-scale Industry"; Prasannan Parthasarathi, *Why Europe Grew Rich*.

Their financial acumen joined with the exposure to the world economy that the three port cities had long enjoyed. The prehistory of these cities as East India Company ports, as hubs of Asian trade in the nineteenth century, and as premier business towns of the British Empire made shopping for technology easy for Indian firms. Economic historians identify four channels through which transactions in useful knowledge can happen – migration of experts, foreign investment, trade in machinery, and state policy. Apart from the state, the other channels relate to labour, capital, and commodity market transactions. In India foreign investment was small overall, but significant in jute and tea. The state was relatively passive in fostering technological learning. The role of labour and commodity markets as conduits of transfer of ideas was considerable. By and large, traded machines, together with migration of engineers and foremen from Britain, fostered the movement of technology between Britain and India.

The factory industry in cotton textiles emerged in the mid-nineteenth century in two cities of western India, Bombay and Ahmedabad. About the same time, a jute textile industry began to grow in Calcutta. Although sources of capital into factory industry varied considerably, in all cases, British technology, machines, and supervisors were critical in the early history of these factories. In jute foreign technology came in via foreign investment. In cotton textiles, overseas marketing contacts of Indian export merchants made the difference. In cotton, entrepreneurship came from among Indian cotton merchants and bankers. The leading ports established by the East India Company were sufficiently linked with the cotton trade of Liverpool and the machine-building industry of Manchester for the cotton merchants to consider stepping into factory production. The combination of trade, financial innovation and cosmopolitanism made the merchants in the three cities quite different in outlook from their counterparts engaged in overland grain trade and moneylending. None of the traditional

artisanal towns became sites for factories because they lacked capital and global exposure, even though they possessed high levels of craft skill.

Although it underestimates how colonialism reduced the cost of acquisition of knowhow, the empire narrative infers correctly that the process could lead to distortions and adverse path dependence. Indian millowners were known to neglect efficiency and innovation. That propensity posed no serious problem until World War I, or as long as their main competitors were high-wage economies in the West. But after the war, the mills faced a growing challenge from a low-wage country, Japan. Japanese success had owed in part to the indigenization of textile machine production, which had made a shift from mule to ring spinning more feasible in Japan.[10] The Indian mills followed a more conservative path. And they needed to change late in the interwar period, when technical efficiency was already low in Bombay thanks to outdated machines, and persistence with British standards made things worse.

One study attributes the conservatism displayed by the Indian factory owners to a preference for risk aversion.[11] Another reading of the conservatism is that the Indian employers in Bombay and Calcutta preferred an employment contract that gave away a lot of authority to train and recruit workers to intermediaries, thus reducing the employers' capacity to restructure the shop-floor. Why intermediary power was elevated in Bombay or Calcutta is a question we need not enter into here. In any case, business leaders responded to the competition by pushing for protectionism. And since some of them also funded the nationalist movement, protectionism had strong political backing behind it.

Too much attention to these perceived Indian "failures" can lead to an oversight of learning by doing at the work site. Recent research has brought a number of examples in

[10] Y. Kiyokawa, "Technical Adaptations"; K. Otsuka, G Ranis and G Saxonhouse, *Comparative Technology-Choice*; Susan Wolcott, "Perils of Lifetime Employment".
[11] Dwijendra Tripathi, "Colonialism and Technology Choices".

clearer view. In the interwar period, the percentage of Europeans among the supervisory staff in cotton mills fell sharply, from well over half to less than a quarter. Research on railway has also shown how frequently British standards were being modified to suit Indian conditions.[12] A great deal of learning by doing had been present in another field of large-scale public intervention, canal construction, where engineers familiar with canal construction in Britain had to deal with problems specific to the Gangetic plains, such as monsoon floods, waterlogging, and malaria epidemic as a result of waterlogging.[13] A different and more costly learning concerned the telegraphic system designed for India by William O'Shaughnessy. Although his system was a brilliant adaptation to local conditions, elements in the adaptation itself proved unworkable inducing a return to imported technology.[14] The diffusion of the stationary steam engine is another example of absorption and adaptation.[15] Learning from British engineers and their progressive substitution for Indian foremen had been proceeding apace in railway workshops, arsenal factories, field telegraphs, cadastral surveys, mineral prospecting, geological surveys, and meteorological services. Recent railway and telegraph scholarship suggests that the real legacy of these public goods was not confined to the technology packages that reached India, or the modifications that these underwent. The legacy rather was a series of positive externalities in the shape of travel, expanding livelihood choices for those able and willing to migrate, information exchange, expanding concept of space, more optimal resource usage, a great deal of learning in the matter of public management and public-private partnership, integration of commodity and factor markets, and reduction of risks of cargo transit.[16]

[12] Ian Derbyshire, "The Building of India"s Railways".
[13] Ian Stone, *Canal Irrigation.*
[14] Deep Kanta Lahiri Choudhury, *Telegraphic Imperialism*.
[15] Jennifer Tann and John Aitken. "The Diffusion of the Stationary Steam Engine".
[16] Ian J. Kerr, *Engines of Change*; Latika Chaudhary and Dan Bogart, "Engines of Growth".

Civil engineering colleges had begun to be established from the mid-nineteenth century.[17] By the time independence came in 1947, the indigenous component in the technical and engineering work-force in the public services was so prominent and so vocal as a lobby, that they could push the case for more public investment in engineering education. If protectionism had been one legacy of the technological paradigm associated with Indian industrialization, the domestic drive for engineering education was its other legacy.

The empire narrative, therefore, is in need of two qualifications. First, by overstating the case for "understanding" machines and underestimating the role of markets (for money as well as machines), the empire story misreads the character of late industrialization. The opposition between "understanding" and "desire" is a rhetorical one. Entrepreneurs solve problems; they do not need to understand everything. Second, being too macro in perspective, the empire narrative misses a variety of learning effects that were present at the shop-floor level. Such learning left long-term and far-reaching effects. Perhaps the most important one was the creation of an engineering corps that pushed for further development of engineering education in India after independence in 1947. Indian advance in engineering was a legacy of the colonial-era industrialization and it has played a role in every episode of rapid economic growth since the end of colonialism.

The artisan entered the empire story as a victim. In the last twenty years, a literature has questioned that assumption, found the response of the artisan to western knowledge to be highly differentiated, and restored to the artisan a capacity to reinvent traditional knowledge in order to make it serve modern uses.[18] This revaluation requires us to develop another

[17] S. Ambirajan, "Science and Technology Education"; Arun Kumar, "Colonial Requirements"; Saroj Ghose, "Commercial Needs".

[18] Reinterpretations of crafts history can be found in Tirthankar Roy, *Traditional Industry*; Roy, "Acceptance of Innovations; "Out of Tradition"; Douglas Haynes, "The Logic of the Artisan Firm"; Haynes, "Artisan Cloth-Producers"; Douglas Haynes and Tirthankar Roy, "Conceiving mobility". The next section is based on this corpus.

perspective on technology, one that places more weight upon private choice than in the other discourses.

Profit

The central proposition of the profit story is that rational economic calculations mattered to the adoption of technology. And yet, the specific example of the artisans suggests that benefit-cost calculus was not a sufficient predictor of acceptance of innovations. Social and cultural factors were important too.

Several million artisans lost livelihoods during the nineteenth century, and many continued to do so in the early twentieth century. It remains difficult to measure the scale of this phenomenon because some who lost jobs were part-time household workers, often women. They gave up craft activity when the male members left home in search of work. The effect of such reallocations of labour upon the household are not well understood. Sometimes, rural craft workers lost access to markets because the more efficient urban craft workers supplied the market better. A few early examples of industrial decline may have owed to the particular conditions of the late eighteenth century.[19] Still, there is little dispute that large fields of craft work represented by cotton spinners and iron smelters disappeared because of cheap imports from Britain.

From 1871, when population and occupational censuses began, the rate of job-loss in the crafts seemed to slow. By 1900, there was a distinct reversal. Between 1900 and 1935, artisan industries contributed positively to the generally robust growth of GDP in industry.[20] Their share in total GDP increased. Cloth production in handlooms, by far the largest craft industry, increased several times between 1900 and 1940 with a constant number of looms.

[19] See, for further discussion, and case-studies, Indrajit Ray, *Bengal Industries*.
[20] S. Sivasubramonian, *National Income*.

Other supporting evidence for a revival comes from the real wages of urban carpenters, blacksmiths, and masons, which steadily increased (and diverged from the wages earned by their counterparts in the villages) in the early twentieth century. In handlooms as well as in the crafts more generally, the increase in income occurred on the basis of a falling employment, which would suggest a major restructuring in institutions and technology. Indeed, the adoption of better tools and processes contributed directly to this transformation.

If these tools and processes represented new knowledge, where did the knowledge come from? Why was it adopted if the crafts did not have an economic future? The examples of handloom weaving and iron manufacture suggest a capacity of the crafts to reinvent themselves.

Some of the most important tools and processes adopted by the handloom weavers in late-colonial India, such as the fly-shuttle slay, the frame-mounted loom, the jacquard, dobby, drop-box, and synthetic dyes, had been invented in Europe between the late eighteenth and the late nineteenth centuries. By 1900, the handloom weavers had also switched from hand spun yarn to the much cheaper machine spun yarn. In artisanal production, borrowing tools and processes made economic sense in certain segments. These were fields, such as fine textiles, where economies of scale were small, and consumers valued product differentiation and craftsmanship. In intermediate goods such as cotton yarn or pig iron, where the scale economies were larger and the final product was a generic good, artisanal production ceased to make economic sense and retreated in favour of machine production. But when consumer demand valued difference, crafts had a chance. In those segments where a positive preference for handmade designs or texture prevailed, importation of technologies reduced costs of production, increased productivity, and enhanced economies of scope.

Such knowledge augmented an already rich resource among certain types of handloom weavers, their craft skills. Among these segments which could combine inherited

skills with borrowed tools, there emerged a class of artisan-entrepreneurs, whom one recent work designates "weaver capitalists".[21] Adoption of new tools, for reasons we shall see, needed the agency of such people. The movement was present in many places, but particularly robust in western India, where the main hubs of cotton, yarn, and cloth manufacturing were located. Here, in a cluster of towns located within easy access of Bombay and yet distant enough to have much lower wages and overhead cost, members of traditional weaving communities from north India and the princely state of Hyderabad established clusters of handloom factories. The weaver-capitalist was sometimes a leading merchant, sometimes a factory-owner, and more often a combination of the two, in these sites.

Some of the prominent towns that have been studied are Sholapur in the Bombay-Deccan region, Salem and Madura in Madras Presidency, and Surat in Gujarat. These clusters produced cloth on a different principle from that in places where the migrants had come from. Whereas in places of origin, weavers worked from within households, in the new clusters they set up workshops that employed wage-workers. Whereas in places of origin they often combined yarn-processing and dyeing with weaving, in the new sites weaving, processing, and dyeing were performed as separate processes. There was a demographic shift as well. The textile towns received migrant artisans from the agriculturally poorer areas. The able-bodied male migrant was a wage-worker, or more rarely a workshop-owner, whereas the women and the older members performed sizing and warping in a separate place, usually owned by another individual.

Salem, Sholapur, and Surat were sites that saw early and large-scale adoption of new weaving tools. Madura was the most famous example of successful switch to tar-based dyes, while retaining the distinctive look of the cloths for which local weaving was already well

[21] Douglas Haynes, *Small Town Capitalism*.

known. The town was especially suitable for wider adoption of new processes. The presence of a large local market that consumed a variety of goods reduced the risks associated with any new idea, and sometimes supplied an incentive to speed up certain processes. The urban market was less sensitive to the agricultural seasons than was the rural market. The rural demand was not only variable by seasons, but also unstable because of the prospect of monsoon failure.

The transition from household industry to wage-based workshop was compatible with the adoption of new tools and processes. In the processing shop, the practice of warping small lots of yarn on sticks or pegs gave way to beams. While family weaving could make use of at the most two looms the factory allowed, even necessitated, the assembly of a number of looms. The traditional household loom was installed in a pit dug in the living room. The pit retained moisture, but did not easily allow the addition of extra attachments to implement uniform tension ("take-up motion"), larger scale (cloth and warp beams), complex designs by manipulating the warp threads (draw-boy harness, dobby or jacquard) or weft threads (drop box). The handloom factories installed more compact frame looms, which were not constrained in this way. From the end of the interwar period, looms mounted on frames were fitted with overhead attachments to weave designs. The frame loom was technically much closer to a power-operated loom, in that fitting an electric or oil-engine motor was compatible with the concept of the frame loom, and many capitalist weavers were actively doing this from the 1940s. On the other side, even such a cheap and flexible innovation as the fly-shuttle slay, remained rare in rural weaving. Neither was the local market large enough to act as an incentive nor was the household organization always compatible with a different style of loom.

A similar process of adoption of new tools occurred in iron and steel. The nineteenth century had begun with a rapid increase in the import of iron goods into India. These imports destroyed the livelihoods of some of the rural iron smelters. On the other hand, because of the new imports, the specialist blacksmith of the large towns could employ their craftsmanship to

better effect. Already in the 1850s, a huge variety and number of hand tools dominated iron import into India from Britain. According to the evidence of two Sheffield masters, the main articles of export to India were "tools of all kinds, more particularly tools for joiners' and carpenters' purposes, files and saws, steel, .. and hardware generally."[22] Other than the railways, the users of these tools were the carpenters and blacksmiths.

In the second half of the century, Indian blacksmiths were beginning to meet some of the emerging demand for consumer goods. With the coming of imported English and Swedish iron, a new urban demand for cutlery grew rapidly. Around 1800, articles of steel in ordinary use, including cutlery, knives and scissors, "are generally imported from England, being very superior to those manufactured in India".[23] By 1900, however, cutlery manufacture occurred in nearly all the cities or within clusters with easy access to mass transportation. The port cities were sites where European ideas of interior decoration were becoming popular, this market too was supplied by Indian blacksmiths and carpenters. Members of traditional blacksmith castes were employed in the railway workshops, in a gun-carriage shop in Madras, a gun factory near Calcutta, and inside the government mint. In this way, the city, the ports, the barracks, and the public works, allowed a convergence to develop between European tools and Indian artisanal capability. Blacksmiths benefited from the unconventional communication opportunities provided by the new sites, while adapting their skills to serve urban household consumption.

Although these were profit-motivated choices, they were taken in a social context. The role of specific consumer preference has been discussed. Moreover, whether in households or in factories, the dynamic segment of the crafts continued to rely on caste and community support. Indeed, migrant groups were often more reliant on such ties and

[22] British Parliamentary Papers 1859 Session 1 (198), *Select* Committee, 245-250.
[23] British Parliamentary Papers 1812-13 (122), *Select Committee*, 365.

affinities than were the sedentary ones. For an individual working within a community, adopting a new innovation without general agreement could be dangerous, whereas collective agreement about the need for a change could ensure the wider diffusion of a new innovation.[24] Craft history provides numerous instances of both types of dynamics. In handloom weaving, for example, successful learning and mass acceptance of new technologies tended to happen in the textile towns. No innovation would be accepted unless endorsed by the most prominent members of the local caste association, or by a sufficiently large number of members. In turn, the leaders were anxious to restrict access to trade secrets, so that associational activity and the endorsement (or otherwise) of technologies became interdependent. Madura's success in dyeing was one example of this caste-cum-guild at work.

The role of internal trade and migration alerts us to another large-scale development that mattered to the diffusion of knowledge, integration of markets within India. Successful knowledge transaction required that trade costs and costs of complementary inputs were relatively low. Numerous borrowed ideas failed in the nineteenth century because the entrepreneurs had underestimated the cost of fuel or transportation. Craft history and the history of the cotton mills prove the point indirectly by showing why innovation and risk-taking was so concentrated. They did because modern factories also needed recruitment of labour on a large scale, low interest rates, low transport costs, and low shipping and insurance costs, and easy access to traded machines and foreign foremen.

The importance of trade cost is shown more directly in the examples of failures of enterprise, such as early nineteenth century experiments in iron smelting. India had plenty of iron ore, forests suitable for conversion into charcoal, and a huge demand for iron goods. From the late eighteenth century, the Company and private traders imported an increasing quantity of iron goods, which went into arsenal manufacture, consumption by European

[24] Roy, "Out of Tradition".

settlers, or bridge building. Artisan communities producing semi-finished iron tended to be located near the sources of ores and worked on a scale and level of capability adapted to meeting local rural demand for iron. Although their own markets were protected by high transport costs, they were not capable of supplying the urban and government demand. British artisans understood that charcoal smelting in the larger-scale workshop (and in some cases a puddling furnace) situated near points of consumption would be a promising business, and they found government officers willing to offer them concessions. At one point in the 1850s, colonial officials invited Swedish iron-makers as consultants to revive a project in the Kumaon hills, the Swedish tradition being considered more familiar with charcoal smelting on a large scale.[25]

All of these enterprises failed, despite the empire taking an unusual degree of interest in their success. They failed because of undervaluation of trade costs. The physical distance between their targeted market, which was the government ordnance stores based in the port city, and the origin of the ore, which occurred in forested uplands without either navigable rivers or roads suitable for wheeled transport, posed an insurmountable problem. The one hypothetical advantage they had was cheap labour. But Indian labour was located near the ores, usually found working within traditional institutions such as the household, and used to operating small-scale units. There was an unbridgeable distance between Indian labour and European workmanship in the large smelting shops. Skilled labour imported from Britain did not provide a solution. Facing a seller's market, the migrants turned unreliable as workers. In common with indigenous smelting, European smelting had to contend with the rising scarcity of wood fuel as forests began to run out in much of the iron-rich areas. Finally, in getting access to both ore and wood, the Europeans ran into problems with those departments of the

[25] Jan af Geijerstam, *Landscapes of Technology Transfer*.

government that looked after property rights over agricultural and common lands. They saw these enterprises as a threat to their main clients, the peasants and landlords.

In metallurgy and engineering, market integration was slow to develop, but it did happen from around World War I, as sources of coal, manganese, limestone and iron became interconnected by the railways. Factories operating on European pattern with blast furnaces, foundry shops, rolling mills, and mechanical forges were set up in rising numbers, partly to meet the huge expansion in demand from the railways for rolling stock, rails, sleepers, wires, bars, and rods. Coke smelting was becoming more common, and the development of mineral prospecting revealed important information about inputs necessary in a blast furnace and available within the easy reach of the railways. An ordnance factory of Calcutta and a civil engineering school in Roorkee had metal-working shops, and by World War I, produced hundreds of locally trained workers with experience in metallurgy. Without these developments it would be hard to explain why Tata Steel, a project conceived in the 1880s, needed more than twenty years before it was considered ready for implementation. Almost from the start, the company owned not only an integrated steel factory, but also mines, transportation, and a coal washery.

Where all three preconditions were present – a promising consumer market that valued skills, cheap factors (labour, cotton, dyes, or ore), and the presence of a collective that was open to new ideas – the state often stepped in as a partner. In handloom textiles, the Industry Departments, the Christian missions, and nationalist volunteers played a role in popularizing improved tools. The state also came in the aid of the fledgling Tata Steel with major railway contracts and tariff protection that saved the infant industry from premature death. But it would be a mistake to see in their efforts, as the campaigners themselves sometimes did, the success of state intervention in the aid of poor, ignorant, backward, and helpless producers. The truth was, the state joined in as a partner when the private producer had demonstrated a promise.

If these examples point to the importance of economic calculations behind the exchange of ideas, the notion that context matters has received a new emphasis in reinterpretations of early modern Indo-European contact in the sphere of knowledge.

Culture

The central proposition of the culture story is that the relationship between parties joining an exchange matters to what is exchanged and how its value is perceived.

Among historians of technological change, there has always been a strong interest in "culture". Max Weber drew a connection between religion and innovation.[26] In recent economic history scholarship, culture as spheres of exchange of knowledge and information has received attention.[27] There is also an interest within economic history in culture as collective behaviour.[28] However, in the context of technological change in colonial India, the analytical interest in culture derives from the particular need to rethink the meaning of Indo-European contact in a colonial setting.

Much recent work in the subject is driven by a reaction to "essentialist" and "diffusionist" models of knowledge formation. Essentialism would refer to a belief that each regional body of knowledge is an autonomous and unique category in itself. Diffusionism can be loosely defined as a theory that claims that useful knowledge has a well-defined origin, from which it travels to other peoples and regions. In the modern era, the precursor to diffusionism was the idea that scientific rationality originated in Europe, and travelled, through conquest and colonialism, to the non-European world, where local cultures had created obstacles to an endogenous development of the scientific spirit. Weber, Karl Marx,

[26] Max Weber, *The Religion of India*; Milton Singer, "Religion and Social Change".
[27] Joel Mokyr, *Gifts of Athena*.
[28] Avner Greif, *Institutions*; Mark Granovetter, "Economic Action and Social Structure".

and numerous colonial writers on India expressed such negative views about Indian culture, though there were differences in the manner in which cultural obstacles were described.[29]

The reaction to diffusionism is as diverse. An Indian nationalistic reaction was to claim that precolonial Indian culture was scientifically, technologically, and educationally more advanced than commonly realized, and that colonialism, through neglect or by design, destroyed scientific knowledge and systems of mass education.[30] Elements of Indian culture seen as obstacles to economically rational actions, such as the caste system or Hinduism, have been reinterpreted more liberally by others.[31]

In recent historical scholarship on Asian societies before and during the expansion of European political power, the outline of another counter-narrative has emerged. Three specific propositions underlie the counter-narrative. First, transactions in knowledge have a deeper, longer, and more global history than that of Westernization. Second, scientific knowledge changes its form and possible use according to context, so that local clusters of ideas are rarely mirror images of the original source. In some cases, the original source cannot even be identified. Third, the process of transaction in ideas was social and political in nature. More than content, the local context mattered in a variety of ways. For example, how borrowed knowledge gained legitimacy mattered more than efficacy in the creation of local conventions of theory and practice. Almost always, borrowed knowledge involved the

[29] See Weber, *The Religion of India*. The evolution of modern science was attributed by later economic historians to the evolution of a "scientific attitude", see Walt W. Rostow, "The Stages of Economic Growth". Others offered a similar analysis based on the role of the caste system, S. Gopal, "Social Set-up".

[30] Dharampal, *Indian Science*; Claude Alvares, *De-colonizing History*. See also D.M. Bose, S. N. Sen and B. V. Subbarayappa, eds., *A Concise History of Science*.

[31] M.D. Morris, "Values as an Obstacle. See also Singer, "Religion and Social Change". The scholarship criticizing Weber is very large. Within this scholarship, Weber"s position has often been misrepresented by both "vulgar" Weberians and their critics, according to David Gellner, "Religion".

intervention of a diverse group of agents, mediators and translators. Their own political status influenced the hierarchy of local and foreign science.

Historians of science working with Indian material have made specific contributions to the new counter-narrative. Inspired by works such as Jack Goody's or Joseph Needham's suggesting that the signifiers of scientific reasoning occurred simultaneously in many world cultures, so that identifying the copyright of any big idea is an impossible quest, they focus instead upon the dynamics of interaction between local and global knowledge.[32] Traditional and local knowledge did not become obsolete in nineteenth century India, but influenced the making of new knowledge and this process was influenced in turn by the relationship between indigenous agents and new actors linked with colonial rule.[33] A recent work argues that the making of knowledge in South Asia was shaped by "material, economic, and symbolic transactions between indigenes and Europeans".[34] And another contends that the making of science in the non-western world is fundamentally a cultural process.[35] The reinterpretation has stimulated research on the process of knowledge formation in the early days of the British Empire in India, when all officially sponsored knowledge-gathering enterprise by Europeans needed to rely on Indian mediation.

This scholarship is neither compelling nor deeply interested in nineteenth century transactions in technology. Where the users of knowledge are discussed, the discussion considers mainly administrative uses such as land surveys or map making, rather than production and trade of goods in the market. When indigenous mediators are discussed, we

[32] *The East in the West*. On Needham, see Francesca Bray, "Technics and Civilization".
[33] See Kapil Raj, *Relocating Modern Science*. "Introduction" in Habib and Raina, eds., *Social History of Science*, proposes that the task of the historian is to explore how science travels from one intellectual context to another. The assimilation process is seen as a problem of epistemology as well as a problem in political history. This historiography deals mainly with the uneasy relation between the state and the research scientist. See also the useful survey in Parthasarathi, *Why Europe*.
[34] Raj, *Relocating Modern Science*.
[35] Pratik Chakrabarti, *Western Science*.

meet the Brahmin scribes, not the merchants. This is a limiting framework if we are mainly interested in technologies, where profit calculations must play some role. It more or less breaks down in the context of nineteenth century diffusion of technological ideas, when industrialization and the mass production of machines and materials limited the capacity of recipients of borrowed knowledge to rework its contents, and when much useful knowledge travelled in the shape of traded objects and manuals.

Subject to that criticism, in one exceptional field the perspective has found a creative application, the practice of medicine, if we can call biological-botanical knowledge a commercial "technology". Medicine represents a uniquely instructive example of interaction between Indian and European knowledge. Most artisanal knowledge remained tacit knowledge imparted by informal master-apprenticeship tradition. Indigenous medicine was an exception. It was usually a preserve of the elite literate groups, more reliant on texts and writing, and involved formal institutions of learning. When this written knowledge encountered European knowledge, it already had a committed following of consumers and practitioners. The fact that the encounter occurred on a somewhat equal footing makes the medicine story different from that of the standard stories of artisanal decline. In turn, Indian theory and practice attracted Europeans not least because the Indian system was sometimes better equipped to deal with tropical diseases and conditions. Therefore, medicine became a fertile ground for a two-way exchange.

The official Indian Medical Service was one of the most organized and scientifically competent public health institutions in the tropical world. Although it did intentionally or otherwise provide a platform for some outstanding research activity in tropical diseases, research was neither a priority nor always feasible given its limited budget. The service, therefore, maintained a generally conservative bearing. In practice, members of the service had to constantly deal with indigenous diagnostic and treatment systems, and a great deal of

indigenous organic resources that had been long in usage for treatment of routine diseases. Doctors, scientists, and administrators, therefore, faced two choices about dealing with such "alternative" medicine, to hierarchize knowledge systems, or to absorb and recycle Indian tradition. Both of these effects were present, even though the former represented the official stance, which in turn, drove many Indian patients away from the public health system.

The problem of public health had become serious in the late nineteenth century because of devastating famines, followed by epidemics of cholera, smallpox, and malaria, as well as the appalling state of hygiene in the Indian quarters of the three port cities that had grown very rapidly in the nineteenth century. These cities from their inception had developed with two identities, a European quarter and an Indian one. Urban planning and management for the Indian side was neglected whereas these were practiced on the European side. Population growth, however, was much faster and population density much higher in the Indian settlement, exposing the latter to waves of plague epidemic at the turn of the twentieth century. These disasters made sanitary engineering and environmental health issues of utmost concern to the public health body.[36] For the ambiguous attitude that Indian patients maintained with respect to public health, and for all of these other reasons, public health drive was filled with tensions caused by competing knowledge systems, and culturalist claims and counterclaims. Alongside, there was also a great deal of informal research, learning, reverse engineering, and revaluation of knowledge.[37]

Conclusion

[36] Deepak Kumar, "Probing History of Medicine".

[37] For further reading on this large and growing scholarship, see David Arnold, *Science, Technology and Medicine*; Projit Mukharji, *Nationalizing the Body*; Mridula Ramanna, *Western Medicine*. One section of the bureaucracy believed that India"s problem was its population, and advocated birth control technology. See Sanjam Ahluwalia, *Reproductive Restraints*.

The three discourses emphasize three quite distinct drivers behind long-term change in useful knowledge. These are, state policy, resource endowments and expected gains, and the context of interaction between people. They do not represent competing approaches. Treating these as substitutes is likely to lead to a misreading of one or the other perspective. For example, teaching the empire narrative in a business history class could lead to confusion between two types of freedom, political freedom and freedom in the market, and an oversight of the different ways that these two freedoms matter to knowledge growth. That each story is useful in itself is hardly surprising. What is surprising is that each one of these scholarships has grown without citing, even taking notice of the other two. The paper, it is hoped, should contribute to weakening the barrier.

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