Useful & Reliable: Technological Transformation in Colonial India

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Abstract

The proposition that Useful and Reliable Knowledge (URK) produced divergent patterns of long-term economic growth implies that such knowledge had weak agency in countries that fell behind. This article rejects such a theory on the evidence of colonial India. Indo-European contacts activated transfer, transplantation, and adaptation in URK; however, the impact was uneven within India. Despite boosting productivity in manufacturing and consumption, large areas were left untouched. These contrasts highlight the differentiated impact of URK on production conditions in India and question its transferability and mode of knowledge exchange under colonialism.

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The introduction to this special issue explains economic historians' recent interest in Useful and Reliable Knowledge (URK). For economic and global history, URK is "knowledge that allows for a sustained rise in labor productivity." That idea informs debates on the origin of modern economic growth, and by implication world inequality.[1] Exchanges on these two topics, now known as the divergence debate, propose that an "enlightened economy" and the development of URK have set the modern West on a distinct economic growth trajectory—one that was late, weak, and even missing in the non-Western world.[2]

Accepting that the distribution of URK could somehow explain world inequality in living standards in the modern world would mean accepting that the knowledge enabling a sustained rise in labor productivity appeared slowly in nineteenth- or twentieth-century India. Most historians of India would find that implication disturbing, given the sheer volume of sources on the quality, diversity, and depth of local knowledge on science and technology. Prasannan Parthasarathi makes the point that India had a well-developed industrial and commercial tradition before colonialism.[3] His robust and valid critique echoes how historians of science view Indian knowledge. But the criticism does not explain what happened to that substantial tradition during the colonial era. India did not become a rich nation, which points to a regression on several levels, first economically, as URK failed to deliver a sustained rise in labor productivity, and second intellectually, in that "Western" knowledge displaced indigenous tradition. In both cases, scholars see colonialism causing this adverse effect.

A closer look at whether URK increased productivity in colonial India could modify this transition model and in turn help us rethink the relationship between knowledge and colonialism. URK did, as this study shows, deliver a sustained rise in productivity in major production fields and changed the quality of life in nineteenth- and twentieth-century India, while large areas remained untouched. This difference was a fundamental feature of the colonial URK. We should, then, reject the broad claim that URK failed to deliver a sustained

[1] Currently, URK "refers broadly to knowledge with a technological impact"; Christine Moll-Murata, "A Streetcar Named 'Utility': Useful and Reliable Knowledge in China in the Second Millennium," URKEW discussion paper 10, London School of Economics, 2013, 8. URK might be a feature of the "enlightened economy," where knowledge obtained from observation and experiments and potentially useful for commercial purposes gains currency (Mokyr, *Enlightened Economy*). According to O'Brien, "Historical Foundations," URK "serves political, geopolitical and economic ends rather than moral or spiritual purposes" (p. 17).

[2] Mokyr, *Gifts of Athena*, illustrates the first part of this proposition with a study of Britain.

[3] Parthasarathi, *Why Europe Grew Rich*.

rise in labor productivity in India as a whole and ask instead why the positive productivity outcome was confined to some fields and not found in others.

This challenges us to consider under what conditions knowledge can leave a positive legacy. The enormous rise in trade, migration, and cross-border investment that went hand in hand with nineteenth-century colonialism and globalization modified the choice set for URK users. Indian and Western knowledge could now be discussed in the public sphere with a much wider set of interested parties than ever. Exchange of ideas had happened before, through processes like the ones Liliane Hilaire-Pérez describes in this issue. In India, however, these occurred through rigid networks of castes and communities. The field of exchange, as well as recording and codification of ideas, expanded enormously thanks to popular printed communication and Western technologies entering via government sponsorship, advertising, manufacturers' agents, traveling artisans, and experts. Indirectly, colonialism had a positive effect by speeding up the flow of URK.

Communication gave producers more options in an integrated market. Whether they used them or were successful did not just depend on colonialism as a political force. It also depended on consumer preferences, intercultural exchange patterns, business culture, institutions, geography, and work practices. The unevenness of URK development—stronger in manufacturing and trade, weaker in agriculture—means that certain factors were beyond the state's or private actors' control. Thus, "situatedness" (see "introduction" to this issue) is central to all the cases discussed in this article.

Two points should now be obvious. The spotlight here is on production, an interest shared with Masayuki Tanimoto's study of Japan in this issue. This article, however, expands "technology" to include the infrastructure and public goods that impacted everyday life, like railways, communication technology, disease control, and disaster prevention. "Colonialism" as used here does not just refer to a type of state. It also includes an economic condition that emerged in the nineteenth century. The relevant ingredients are the integration of markets for goods (including machines) and services (including skilled people) and the public sphere. Several examples discussed here demonstrate the significance of colonialism as a marketplace and as a state. They lead to a discussion on the relationship between URK and the Indian context by concentrating on types of users—mechanized factories, artisans, the state, peasants, and consumers.

Does the History of Science Inform the History of Technology?

A large part of the historiography of science in a colonial setting deals with the encounter between Western and local knowledge. For colonial administrators and wealthy Indians, science and technology were the best gift an industrializing Britain could offer India. The scholarship suggests that the status of local approaches to URK changed during colonial rule. The process eradicated Indian knowledge in some cases; more generally, it led to identifying Western science and modernization, and formalizing the teaching of science and technology, which again could push local knowledge cultures—from studying classical languages to craft skills—into obscurity.[4] In the process, local approaches to knowledge and its usefulness, from Buddhist philology to traditional medicine, became ossified as "tradition" and in turn induced some nationalists to try to rediscover such constructions as "Hindu science."[5]

The scholarship also questions "diffusionism": the belief that modern scientific and technological ideas spread outward from a well-defined Western source, owing to their inherent strengths.[6] Diffusionism has been subject to criticism. It was probably mediated more by colonial power relationships than usefulness or reliability—and local agents mediated diffusion. The local agents' opinions, priorities, and involvement in translating the exchange of ideas mattered to what was adopted and how it was modified.[7] One scholar refers to this process as localization, the direct opposite of globalization.[8]

These theories of mediated knowledge exchange are a useful starting point for the historiography of technology in colonial India (1858–1947). The parallel between science and technology is obvious. Precolonial India had a rich industrial and commercial tradition. Colonialism brought Western contacts and market integration on a global scale. Cosmopolitanism sped up knowledge exchange, recording of data, and codification of knowledge. Globalization and the Industrial Revolution had enabled many industrial ideas to sell throughout the world in the form of machines and manuals. Nineteenth-century scientists

[4] Dharampal, *Indian Science*; Alvares, *Decolonizing History*; Bose, Sen, and Subbarayappa, *Concise History of Science*. On the link between science and modernization: Kumar, "Science and Society"; Nandy, *Science, Hegemony and Violence*; Baber, *Science of Empire*; Prakash, *Another Reason*; Arnold, *Science, Technology and Medicine*; Habib and Raina, *Social History*.

[5] Cohn, *Colonialism*; Washbrook, "South Asia."

[6] Raj, *Relocating Modern Science*.

[7] For case studies from colonial India and Ottoman Turkey: Günergun and Raina, *Science between Europe and Asia*.

[8] Raina, "Travelling both Ways."

working in India used South Asian geological, biological, and climatological data to offer a new understanding of plate tectonics, tropical storms, and tropical diseases.[9] The extensive surveys published on producers and consumers of artisanal goods, along with ethnographic data, provided a lot of information on traditional production and consumption. These information resources had no precedence: a variety of useful knowledge entered a previously nonexistent public sphere. Recent studies using regional language sources show how this public sphere grew, producing in turn books, pamphlets, manuals, newspaper campaigns, and offbeat genres like travelogues.[10] The emerging communication process involved the state, institutions, professions, scientists, bureaucrats, and businesses.[11]

The choices for producers and consumers expanded. The consequences are not obvious. Local situations shaped the usefulness of ideas. While Western technology destroyed artisanal capability in some textile industries, for example, elsewhere selective borrowing of tools and processes reinforced small-scale and craft technologies. Differences stemmed from patterns of consumption and the type of craft skills involved. The fact that Bombay cotton merchants could easily buy machines and hire engineers from Manchester in the United Kingdom helped western India's mill industry. Developing skills and on-the-job training posed a significant new challenge. European artisans believed that, with its plentiful wood and iron ore, India was a fertile field for large-scale charcoal iron smelting. It failed because they underestimated transportation costs or overestimated charcoal supply. In fields where the colonial state was directly engaged, like railways and canals, India's geography and traditions constantly challenged engineers' inherited knowledge.

In common with the history of science, the Westernization of technology existed alongside "localization." There is, nevertheless, a difference between science and technology. A study of URK needs to focus on users and their perception of reliability. Not necessarily a political variable, the standard quantitative measurement of URK is productivity.

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[9] For examples: Roy, *Natural Disasters*.

[10] On craft surveys: Roy, *Crafts and Capitalism*. About manuals on agricultural improvements in regional languages: Ghosh, "Colonial State." For writers on railway travel: Mukhopadhyay, "Wheels of Change?" For useful insights and a different perspective on the railways: Sinha, *Communication and Colonialism*.

[11] The Society for the Diffusion of Useful Knowledge (1830s–1840s) diffused Western science and imported books. Wealthy and educated Indians recorded indigenous agronomic practices; Bayly, *Empire and Information*, 215–21.

Discussions on technology in colonial India are divided. The pessimistic view is that Western technology, imposed by forced free trade and a despotic state, depressed indigenous innovation; the more mixed view acknowledges that colonialism also fostered capability.[12] Which of these positions do the data on productivity confirm?

Did Productivity Rise in India?

Productivity statistics suggest that URK aided economic growth in one field and bypassed others. Table 1 shows the gross domestic product (GDP) per worker in India between 1900 and 1946, when income data were reliable. The economy is divided into two broad segments, agriculture and industry plus services. GDP per worker more than doubled in the nonagricultural sector but did not change in agriculture. The productivity gain in industry and services followed an increase in work intensity. The data show a drop in part-time work and work for women at this time.[13] However, technological change also played a role.

<<Table 1. Estimated Handloom Weaving Productivity in India >>

Productivity grew in three main fields. The first gain was in handicrafts in general (figure 1), particularly cloth handloom weaving. As the data in table 1 show, between 1900 and 1930 the volume of handloom-woven cloth doubled, on the same number of looms. This was a striking but not exceptional phenomenon in light of the much faster power looms. Between 1870 and 1931, employment in the handicrafts fell by 2 to 3 percent a year, but gross income increased. Productivity per factory worker, due to growing industrial employment in factories, rose to five times higher than for a handicraft worker in 1900. Employment in British India factories increased from less than 1 percent of industrial employees in 1860 to 11 percent in 1938.

<< Figure 1. National Income in India, 1900–1945>>

The next productivity gain was in modern transportation, especially railways. As John Hurd shows, the railways reduced the average cost of transporting goods by over 90 percent compared with the pre-railway long-distance trade, which relied on bullock caravans, carts, and boats. Railway freight soared from 3 million to 120 million tons between 1871 and 1929. The huge drop in average transport costs should show significant gains; trade growth figures,

[12] For negative views: Headrick, *Tentacles of Progress*; for mixed views: Tripathi, "Colonialism and Technology Choices."
[13] Roy, *Rethinking Economic Change*.

however, are exaggerated, because the railways took some trade from older systems.[14] While improving trade, the railways also improved their own productivity. Between 1865 and 1930, employment in India's railway system, then one of the largest in the world, increased from 34,000 to 790,000.[15] The freight carried per employee increased from 88 to 151 tons.

Although productivity per person in agriculture stayed the same, production conditions were not stagnant (see figure 1). In the late nineteenth century, cultivation expanded considerably, aided by canals constructed in the north Indo-Gangetic Basin. National income in agriculture increased by 50 percent, just like the net sown area, between 1871 and 1911. After that, canal construction declined along with the net sown area, while income from agriculture stagnated. The accelerated population growth from 1921 was mainly absorbed in the cities, industries, and services. Output per worker in agriculture was lower than in 1911. Even at the best of times, URK did not drive agricultural growth. It is easier to understand the reasons for the different URK agency through case studies, starting with factories and artisans.

How Factories Selectively Adopt Technologies

Some experiments to establish factories in the early nineteenth century failed, such as large-scale iron smelting. India was rich in iron ore and had forests suitable for charcoal production. From the late eighteenth century, the East India Company and private traders increasingly imported iron goods for arsenal manufacture, consumption by European settlers, and bridge building. Artisans worked on semifinished iron near the ore sources and adapted their scale to local rural demand. Although high transport costs protected their markets, the artisans could not meet urban and government demand. Charcoal smelting in large-scale workshops (also in puddling furnaces) situated near consumption points was a potential venture. British immigrant artisans spotting this opportunity found government officers willing to offer concessions. Andrew Duncan in western Bengal around 1810 and Josiah Marshall Heath in Porto Novo near Madras in the 1830s made serious attempts. When these failed, officials invited Swedish ironworkers as consultants to revive a project in the Kumaon hills, as the Swedes were traditionally considered more familiar with large-scale charcoal smelting.[16] That also failed.

[14] The potential income from trade expansion is usually underestimated in national data sets, which take wages in the services to represent productivity.
[15] Hurd, "Railways."
[16] Geijerstam, *Landscapes of Technology Transfer*.

The entrepreneurs anticipated demand but faced enormous supply problems. The distance between their target market, the government ordnance stores in ports, and the ore in upland forests, with no navigable rivers or roads suitable for wheeled transport, posed insurmountable problems. The entrepreneurs' one hypothetical advantage was cheap labor. But that labor was near the ore reserves, applying traditional methods and used to operating small-scale units. Workers hired from Britain proved to be unreliable. Local and Indo-European factories had to contend with the rising scarcity of wood fuel in the forests beside iron-rich areas. To access ore and wood, the Europeans ran into problems with the revenue department in charge of agricultural and common land property rights.[17]

Large-scale metallurgy grew, but only in the late nineteenth century once mass transportation and communication had eased supply problems. Cotton and jute textile mill industries were the significant success story of the nineteenth century. Between 1865 and 1914, the number of modern mechanized mills producing yarn and cloth grew tremendously from 10 to 271 (Bombay Island and Ahmedabad), and average daily employment rose from a few thousand to 260,000. The growth happened despite no form of state aid, such as tariff protection, subsidized inputs, or privileged access to know-how. Around the same time, the jute textile industry was growing near Calcutta. British technology, machines, and supervisors played a crucial role in the early history of such cotton and jute factories.

In some sectors (for example, jute), foreign technology came via foreign investment. In cotton textiles, Indian export merchants' overseas contacts helped. Economists lament that trade-induced specialization in agricultural exports curbed developing countries' capacity to industrialize; they overlook that agricultural exports gave the merchants purchasing power, enabling them to purchase foreign machines and hire engineers. The merchants with access to the ports established by the East India Company—Bombay, Madras, Calcutta, and Karachi—had sufficient links with the Liverpool cotton trade and Manchester's machine-building industry to step into factory production. Through the combination of trade, financial innovation, and a cosmopolitan environment, merchants were more informed about markets and technologies abroad than their counterparts engaging in overland grain trade and moneylending.

Obtaining technology may not have been a problem. Achieving best practice was another matter. Millowners ignored shop-floor practices and in-house training. The machine-worker

[17] Roy, "Did Globalization Aid."

ratios were considerably lower than in Europe, America, and Japan. That difference was acceptable until World War I, when India's main competitors were high-wage economies in the West. After the war, the mills faced a growing challenge from a successful low-wage country, Japan. The indigenization of textile machine production had enabled Japan to shift from mule to ring spinning, and as this was a less skilled and therefore lower-paid operation, more women entered the workplace.[18] The Indian mills followed British tradition in persisting with mule spinning, which required heavier labor, and a male workforce in the spinning shops.[19] That workforce was probably more unionized—men were in the majority and more politically organized than women—and therefore resisted managerial moves to improve labor-machine ratios.

The quality-of-labor issue in textile factories has evoked debate in the comparative history of technology absorption during industrialization. Some suggest that productivity was low because of worker preference and union resistance, forcing managers to keep wages low.[20] Others consider that agricultural productivity determined wages. Managers and owners reaped the benefits of low wages as long as they competed with high-wage economies.[21] When the competition became serious, individual mills failed to raise productivity, depending on how much they relied on existing labor institutions.[22]

Late industrialization with borrowed technology is likely to cause problems with the quality of labor: developing skills is a slower process than installing machines. The slow progress with skills was an oversight by millowners, also reflecting the low priority given to technical training in the colonial education system. An open labor market can mitigate this issue. Since the factory owners could more easily hire abroad than their Japanese counterparts, modern industries relied heavily on European and, in steel, American workers. Tata's steel factory (established 1907) recruited many foreign engineers in all its departments. Specific engineering divisions, such as steel rolling, wires and cables, and tinplate, required foreign workers. In tinplate, almost the entire engineering workforce came from Wales, because the process of rolling thin sheets of steel for tin containers had developed there. Glassmaking

[18] Kiyokawa, "Technical Adaptations"; Otsuka, Ranis, and Saxonhouse, *Comparative Technology Choice*; Wolcott, "Perils of Lifetime Employment Systems."
[19] Kiyokawa, "Technical Adaptations."
[20] Wolcott, "Perils of Lifetime Employment Systems"; Wolcott and Clark, "Why Nations Fail."
[21] Bishnupriya Gupta, "Work and Efficiency in Cotton Mills: Did the Indian Entrepreneur Fail?," working paper, University of Warwick, 2003.
[22] Roy, "Role of Labour Institutions."

from sheet glass required high artisanal skills for tasks such as cutting. But cutters were in short supply because this was a new process, and a poorly trained cutter could ruin the glass. To save money, the industry was forced to employ mainly Indian cutters, even though Europe still had the experts. In cotton textiles, foreign engineers came as machine operators, representing the firms that made and supplied the machines.

Yet in the long run, learning-by-doing, learning-by-observing, and adaptation processes occurred on an extensive scale. By 1930, Indians had completely replaced European supervisors in the cotton mills. The scenario of learning from British engineers and then substituting them for Indian supervisors had been progressing apace in railway workshops, arsenal factories, field telegraphs, cadastral and geological surveys, mineral prospecting, and meteorological services. Tata Steel, to survive a crisis in the 1920s, shed many expensive foreign engineers without serious consequences.

Formal training aided the process of absorbing and adapting new technology. Civil engineering colleges were established from the mid-nineteenth century.[23] Around 1900, an ordnance factory for defense production in Calcutta and a civil engineering school in Roorkee had metalworking shops, and by World War I, together these trained hundreds of local workers in metallurgy. By the time independence came in 1947, the indigenous component of the technical and engineering workforce in public services was so prominent and so vocal as a lobby that they could push for more public investment in engineering education. If protectionism was one legacy of industrialization in India, the domestic drive for engineering education was another. Protectionism and activism in the engineering lobby matured after independence.

Reinventing Tradition in the Craft Industries

In contrast with the factories, the transition in handicrafts saw local knowledge taking center stage. The traditional view was that artisans fell victim to specialization on a world scale as a result of free trade and industrialization in Western Europe. These joint forces led to a "deindustrialization" and destruction of accumulated industrial knowledge in poorer economies. In recent decades, scholars have restored the artisan's capacity to reinvent

[23] Ambirajan, "Science and Technology Education"; Kumar, "Colonial Requirements"; Ghose, "Commercial Needs."

traditional knowledge and make it serve modern uses.[24] Western knowledge frequently supplemented that process, consistent with income and productivity data.

Artisans in India did suffer a decline. Several million lost their livelihoods during the nineteenth century and beyond. The deindustrialization theory applies here to iron, steel, and cotton textiles, as a part of the indigenous artisanal industry died out owing to cheap iron manufactures and cotton yarn imports from Britain.[25] From the eighteenth century, iron was one of Britain's major imports to India, and by the late nineteenth century, manufactured iron and cotton textiles were the dominant commodities in the import basket. The decimation of crafts caused a loss of knowledge in extracting and using local materials.[26] Shipping and shipbuilding suffered the same fate with the advent of steam.[27] It is difficult to measure the scale of this phenomenon because, especially in textiles, it was mainly part-time home workers who lost their jobs. But part-time women workers often gave up industry more readily when the male members of their families left home in search of full-time industrial work elsewhere. The process led to a fall in employment and a rise in work intensity, also due to specific conditions in industry, but not deindustrialization.[28] Population and occupational censuses from 1871 show a slowing down of job losses in the crafts. By 1900, there was a reversal within the major crafts, including textiles and iron. Productivity grew, and evidence of a revival are the real wages of urban carpenters, blacksmiths, and masons, which increased (unlike their rural counterparts' wages) in the early 1900s.[29]

Technology contributed to the revival. The major tools and processes adopted by handloom weavers in late colonial India, such as the fly-shuttle slay, the frame-mounted loom, the jacquard, the dobby, the drop box, and synthetic dyes, had been invented in Europe centuries earlier. By 1900, handloom weavers had switched from hand-spun yarn to the much cheaper machine-spun yarn. The surviving artisans operated in fields with low economies of scale, where consumers valued product differentiation and craftsmanship. With these parameters, neither the weaving machine nor the motive force changed readily. Borrowing tools was

[24] For reinterpretations of crafts history: Roy, *Traditional Industry*; Roy, *Crafts and Capitalism*; Roy, "Out of Tradition"; Haynes, "Logic of the Artisan Firm"; Haynes, "Artisan Cloth-Producers"; Haynes and Roy, "Conceiving Mobility." The next section is based on these works.
[25] Bagchi, "Deindustrialisation in Gangetic Bihar"; Bagchi, "Deindustrialization in India."
[26] Bhattacharya, "Iron Smelters"; Biswas, "Iron and Steel"; Roy, "Did Globalization Aid."
[27] Sangwan, "Indian Response."
[28] For case studies: Ray, *Bengal Industries*.
[29] Roy, "Globalization."

piecemeal and compatible with the traditional hand-driven loom. New processes substituted natural for coal dyes, or genuine gold or silver thread for synthetic substitutes, sped up subsidiary processes like warping, or added loom attachments to manipulate shuttles like the drop box.[30] Such knowledge augmented handloom weavers' already-rich resources and design skills; by contrast, in intermediate goods such as cotton yarn or pig iron, with higher economies of scale and standardized end products, artisanal production retreated in favor of machines.

From segments that could combine inherited skills with borrowed tools emerged a class of artisan-entrepreneurs, designated weaver capitalists in a recent work.[31] The adoption of new tools needed such people, and this movement was present in many places but particularly robust in western India's main cotton, yarn, and cloth manufacturing hubs. In a cluster of towns within easy access of Bombay, yet distant enough to have much lower wages and overhead costs, traditional weaving communities from north India and the princely state of Hyderabad established handloom factories. The weaver-capitalist was sometimes a leading merchant, sometimes a factory owner, and more often a combination of the two.

Prominent towns were Sholapur in the Bombay-Deccan region, Salem and Madura in Madras Presidency, and Surat in Gujarat.[32] Unlike in the migrants' place of origin, where weavers worked at home, the new clusters produced cloth by setting up workshops that employed wageworkers. Whereas the weavers originally combined yarn processing and dyeing with weaving, at the new sites weaving, processing, and dyeing were separate processes. Migrant artisans came to the textile towns from the agriculturally poorer areas. The male migrant was a wageworker, while women and older members did sizing and warping in a separate place, usually owned by another individual.[33]

Salem, Sholapur, and Surat saw early and large-scale adoption of new weaving tools. Madura switched successfully to tar-based dyes while retaining the distinctive and already-renowned look of local weavers' cloth. This temple town was especially suitable for wider adoption of new processes because thousands of pilgrims came there. Moreover, its large local market with a wide variety of consumer goods reduced the risks associated with new ideas and provided an incentive to speed up processes. Such an urban market was less sensitive to the agricultural

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[30] Roy, *Crafts and Capitalism*.
[31] Haynes, *Small Town Capitalism*.
[32] Roy, *Crafts and Capitalism*.
[33] Roy, *Rethinking Economic Change*.

seasons than rural markets, where demand not only varied according to the time of year but also was unstable as a result of the prospect of drought from monsoon failure.

Although tools like the fly shuttle were easily compatible with the simpler looms in households, the factory setting enabled the adaptation of more complex and large-scale ideas. In the processing shop, the practice of warping yarn on sticks or pegs gave way to beams. Family weavers could use at most two looms, whereas a factory accommodated several dozen. The traditional household loom was installed in a pit dug in the living room. The pit retained moisture but did not easily allow attachments to implement uniform tension ("take-up motion"), larger scale (cloth and warp beams), complex designs that manipulated warp threads (drawboy harness or the dobby, and jacquard), or weft threads (drop box). The handloom factories installed more compact frame looms that were not constrained. From the 1940s, looms mounted on frames had overhead attachments to weave designs; technically, they came much closer to a power-operated loom. Indeed, many capitalist weavers fitted an electric or oil-powered motor to a loom. In rural weaving, however, even a cheap and flexible innovation such as the fly-shuttle slay remained rare. Rural markets were too small to be an incentive, and households could not cope with a different style of loom. These factors limited the spread of more efficient production technology.

A similar selective adoption combined with adaptation occurred in iron and steel. Rapidly increasing imports of iron goods destroyed the livelihoods of rural iron smelters in the nineteenth century. On the other hand, thanks to the new imports, specialist blacksmiths in large towns could employ their craftsmanship to better effect. According to two Sheffield masters, the items exported to India were "tools of all kinds, more particularly tools for joiners' and carpenters' purposes, files and saws, steel, . . . and hardware generally."[34] Besides the railways, carpenters and blacksmiths used these tools.

Around 1800, ordinary steel items such as cutlery, knives, and scissors were generally imported from England, because these were ordinarily of better quality than the indigenous alternatives, or indigenous alternatives did not exist. As imports of British and Swedish iron created a new urban demand for cutlery, blacksmiths began to meet the demand for consumer goods. By 1900, cutlery was manufactured in nearly all cities or within clusters with easy access to mass transportation. European interior decoration ideas were becoming popular in

[34] British Parliamentary Papers, 1859 Session 1, *Select Committee to Inquire into Progress and Prospects for Promotion of European Colonization and Settlement in India Report*, 245–50.

port cities, a market that blacksmiths and carpenters were also supplying. Members of blacksmith castes found jobs in railway workshops, at a gun carriage shop in Madras, at a gun factory near Calcutta, and at a government mint. In this way, the city, the ports, the barracks, and public works enabled a convergence of European tools and Indian artisanal capability. Blacksmiths benefited by observing new consumer goods in use and coming into contact with European artisans at these new sites, adapting their skills to serve urban household consumption.

The new tools and processes did not spread automatically to traditional crafts but needed capitalist and government intervention. The revival of the crafts, then thought to be depressed, became a nationalist demand after the 1940s. The idea had taken shape much earlier among provincial officers, inspired by pre-Raphaelites in Britain.[35] Although the federal government did not take much interest in crafts, this allowed the provincial governments to step in, but only on a very limited scale owing to funding constraints. Between 1895 and 1910, the provincial authorities produced by far the most detailed surveys on crafts. In handloom textiles, industry departments, Christian missions, and nationalist volunteers played a role in popularizing improved tools. These agents' capacity to make a difference was limited, however. More often, capitalists led the process of change. Some were also social and political leaders. That leadership enabled them to promote—and overcome local resistance to—new ideas. Biographies of prominent artisan-capitalists illustrate this agency. Prem Chand Mistry of Kanchannagar, having started as a generic metal toolmaker in the 1890s, ended up running a large workshop using an oil-powered engine to drive lathes. L. V. Tikekar, a weaver-capitalist from Sholapur, set up the town's first and largest handloom factory in 1899, pioneered the use of the powerloom at a handloom site, and set up a factory manufacturing looms and equipment. Tulasi Ram of Madura, a member of the town's Sourashtra weaving community, was a textile dyeing technologist who revolutionized yarn dyeing in Madura and stimulated his entire community's handloom weaving enterprise. P. Theagaraya Chetty, a weaver-capitalist and leader of the Justice Party, was instrumental in spreading the fly-shuttle pit loom in Madras Presidency. Mohammad Yaar Khan, a merchant-manufacturer in Moradabad's metal product industry, introduced standardization and quality control in the engraved brassware export trade.

[35] Roy, *Crafts and Capitalism*.

Why was indigenous leadership so important to innovation? In the crafts, quality control and standardization were serious issues, especially for capitalistic businesses targeting distant markets. Standardization meant not only making identical units of a product but also creating the perception that the producer could deliver identical quality to every buyer. The absence of copyright protection made producers anxious to hide what they knew, which surely did not help innovation or diffusion. Social and political leaders could ensure that if colleagues followed the producers' example, their credentials would be recognized and protected.[36]

The dynamic segment of crafts, in both households and factories, still depended on caste and community support. Migrant groups were more reliant on such ties and affinities than indigenous people. It could be dangerous for an individual to adopt an innovation without their community's general agreement, whereas collective agreement about the need for change could ensure the wider diffusion of a new innovation.[37] Craft history provides numerous instances of both dynamics. In handloom weaving, successful learning and mass acceptance of new technologies tended to happen in textile towns. No innovation was accepted unless endorsed by the prominent members of the local caste association, or 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 an example of this caste-cum-guild at work.

Finally, the wider use of the stationary steam engine and faster transportation had a significant impact on the businesses that sustained the economies of many small towns. Examples include cloth making on a small scale and rice, sugar, and oil mills, which in turn created work for peddlers, transporters, traders, and bankers.[38] The colonial state, through its construction activities and materials purchasing policy, was potentially a big agent in technological change, but it played a controversial role.

Application of URK in Public Goods and Infrastructure

The East India Company from the late eighteenth century until 1857 and the British Indian government until 1947 took a great deal of interest in sponsoring certain technologies that could reinforce the state's fiscal and military capacity. The numerous interventions included

[36] Roy, *Business History of India*.
[37] Roy, "Out of Tradition."
[38] Sarkar, *Technology and Rural Change*; Tann and Aitken, "Diffusion of the Stationary Steam Engine."

road building, steamships for inland navigation, and constructing irrigation canals or river embankments in the early to mid-nineteenth century; railways and intercontinental telegraph in the 1850s; and crop research in the late nineteenth century. In a more disjointed way, state medical experts and engineers who were not commissioned for research conducted studies of the environment, diseases and pathogens, and knowledge practices.[39] Much of this was collecting data, but cases such as the Bay of Bengal storms led to systematization.[40]

State sponsorship played a crucial role in building more substantial large-scale infrastructures. Collaboration between public offices and private agents mostly determined the choice of technology, reflecting both the ideological resistance to too much state involvement and the state's limited capacity regarding finance and access to information. To construct the railways (1853−78), for example, private companies raised capital from the market, the state's initial involvement being a profit guarantee.

It is not surprising therefore that the historiography of state-mediated URK is ambivalent about the state's role. A broadly negative view is that the technologies thus imported were superior to Indian alternatives, but that the state did not do enough to spread their use throughout society. Instead, the state was too focused on technologies that raised revenue or served defense. The critical perspective, especially in the railways and telegraph, rests on a distinction between "cultural diffusion" and "geographical relocation."[41] Relocation arguably did not encourage diffusion; the benchmark of diffusion is the prospect that society would participate widely in innovation.

Imperial rule, according to critical views, led to the transfer of many Western technologies to Asia and Africa. But rulers did not effectively teach the subjected societies to "understand, and not just desire, the alien machinery."[42] A biased and Westernized education system, designed to create loyalties and dependencies rather than capabilities, compounded conditions. Furthermore, the empire encouraged those knowledge packages that were useful to the imperialists either in the business of governance or in enhancing expatriate capital.[43] This view of technology parallels the diffusion of scientific ideas, exemplified by Roy

39 Bernstein, *Steamboats on the Ganges*.
40 Roy, *Natural Disasters*.
41 Headrick, *Tentacles of Progress*, 12-13.
42 Headrick, *Tentacles of Progress*, 16.
43 Headrick, *Tools of Empire*; Baber, *Science of Empire*; Inkster, "Colonial and Neo-colonial Transfers."

MacLeod, who sees technology as "a purveyor of solutions to the needs of imperial governments."[44]

Railways figure prominently in this discourse. India was the site for constructing an extensive railway system. The connection with Britain through trade, investment, and colonialism was crucial for the decision to build the railways and the construction method. A buy-British bias in procuring rolling stock and locomotives weakened the potential spillover from the railways. Until 1914, the railways did not stimulate the development of an indigenous metallurgical and engineering industry. Funded partly from capital raised in London and partly by Indian taxpayers, the railway's impact on the domestic financial market was weak. A similar argument applies to the state-controlled telegraph—that dependence on British technological precedence limited its spillover effects on knowledge making in the colony.[45]

The revisionist view on this subject, however, changes the discourse. Revisionists are less sure about the superiority of borrowed knowledge but recognize its failures and transformations, attributing them to geographical, cultural, and established situations. For example, a study of the state's efforts to promote coal-fired steamboats in the lower reaches of the Indus river system shows how river morphology and the tropical monsoon environment challenged early steam navigation.[46] Neither the colonial officials who supported private enterprise nor the firms that built the boat engines and bodies in London had hands-on knowledge of the conditions of use. Ultimately, smaller local boats persisted alongside steamboats, and these were cheaper than riskier bulk transportation.

The railway development story features numerous examples of local adaptation. The construction of the "broad-gauge" railway system sponsored by private enterprise relied on local institutions, work practices, and materials.[47] Railway research shows how frequently British standards were modified to suit Indian conditions.[48] More significant are the state-sponsored (including princely states) metre-gauge and narrow-gauge railway systems. These were clearly a cheaper and more appropriate solution for the engineering challenges posed by the Deccan uplands, unlike the relatively flat terrain of the Indo-Gangetic Basin, which has main broad-gauge lines. Adaptations took place in another field of large-scale public

[44] MacLeod, "Nature and Empire," 5.
[45] Ghose, "Commercial Needs"; Lahiri Choudhury, "Beyond the Reach."
[46] Dewey, *Steamboats on the Indus*.
[47] Kerr, *Engine of Change*.
[48] Derbyshire, "Building of India's Railways."

intervention, canals, where engineers familiar with canal construction in Britain had to deal with problems specific to the Gangetic plains, such as monsoon floods and waterlogging, along with the ensuing malaria epidemics.[49] A more costly adaptation process was the telegraph system, designed especially for India by William O'Shaughnessy. Although his system was adapted to local conditions, certain elements proved unworkable, and he had to revert to imported technology.[50]

Other revisionists broaden their analysis of large-scale infrastructure's impact beyond the underlying motive or construction method, to the utilization of these projects. User-oriented studies reach a distinctly less pessimistic conclusion on the railways, stressing their positive externalities generated by market integration and falling trade costs.[51] Railways were built for strategic reasons and used as a business resource by hundreds of thousands of petty traders and migrant workers. In short, the railways had a deep transformative effect on the technology of services and professions. An older study of the telegraph highlights the importance of "communication" costs (transaction in modern parlance) as a business cost, and how the telegraph lines reduced that substantially. "English and Indian businessmen now had a source of almost instantaneous information concerning shipping, weather, and the prices of commodities."[52] In an economy where agricultural commodity trade dominated private capitalistic enterprise, the telegraph served as a business development tool, an outcome overlooked by earlier scholarship. These technologies, by greatly reducing transaction and communication costs, encouraged travel, expanded livelihood choices for those able and willing to migrate, facilitated information exchange, expanded the concept of space, induced more optimal resource usage, stimulated a great deal of learning in public management and public-private partnerships, integrated commodity and factor markets, and reduced cargo transit risks.[53]

Revisionists will not deny that the railways' externalities could have been greater if India had been an independent nation. Until World War I, the majority of railway rolling stock came

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[49] Stone, *Canal Irrigation*.
[50] Lahiri Choudhury, *Telegraphic Imperialism*.
[51] Bogart and Chaudhary, "Railways in Colonial India"; Dave Donaldson, "Railroads of the Raj: Estimating the Impact of Transportation Infrastructure." NBER working paper no. 16487, 2010; Burgess and Donaldson, "Can Openness Mitigate"; Tahir Andrabi and Michael Kuehlwein, "Railways and Price Convergence in British India," July 31, 2009, http://dx.doi.org/10.2139/ssrn.1442013.
[52] Gorman, "Sir William O'Shaughnessy," 601.
[53] Kerr, *Engines of Change*; Bogart and Chaudhary, "Engines of Growth."

from Britain. A complex logic lay behind the buy-British policy. Initially, construction was in private hands, and the government clearly did not want to get involved in production decisions. Protection of intellectual property rights was an established principle in nineteenth-century Britain. It required companies that operated the railways to buy British goods rather than copy these at production sites in India. The buy-British policy was a sentiment shared by many in the engineering corps. Bureaucratic anxiety over standardization often constrained choices between Western and local production of similar goods. India did not yet have reliable institutions for standardization, ideally a public good. The state made only feeble efforts in this direction.[54] The great paradox was not the railways but agriculture—peasants benefited the least from processes that increased production capacity.

~~The Problem of Agriculture~~

Since peasants were the main taxpayers, public and private interest in agricultural improvement overlapped. The state built major canal projects, though these were confined to regions that already had sufficient surface water. Despite occasional campaigns, the state failed to change agricultural implements and made a rather small and localized impact with biological inputs like seeds and fertilizers. There was a tendency to use iron instead of wood, leading to better-quality ploughs and irrigation equipment. In the early twentieth century, agricultural scientists and economists advocated a heavy plough and deep ploughing for dry areas. Although partially successful in Punjab, elsewhere their diffusion was limited. In the interwar period, the government established a chain of agricultural research stations. In particular, the station at Pusa identified superior wheat strains by selecting from hundreds of indigenous varieties. These new seeds became popular.[55]

There is still no explanation why such activities did not spread more widely. One obvious answer is that new seeds and biological inputs had a complementary relationship to water, restricting almost all changes that increased yield to irrigated or "wet" areas. Extracting water from underground aquifers required a scale of private investment beyond the means of the richest peasants. Another obstacle was a weak extension effort. The government's

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[54] Roy, "Origins of Import-Substituting Industrialization."
[55] Pray, "Impact of Agricultural Research"; Pray, "Economics of Agricultural Research." On early agricultural research: Randhawa, *History of Agriculture*, ch. 27, 34–37. Rare industry-sponsored research on natural indigo claimed its unique properties; Kumar, *Indigo Plantations*.

propaganda machine was inadequate or ineffective for new seeds. The only agency that worked was rich peasants, or if some of them became seed merchants. This was the situation in regions where peasants were already relatively well-off, such as the Punjab canal colonies. These were the exceptions. For the most part, little was done or could be done to mitigate pervasive and acute seasonal water scarcity.

New and Hybrid Knowledge in Medicine

In the early 1900s, several inexpensive machines and consumer goods "radically transformed key areas of Indian life."[56] Examples are the sewing machine, the bicycle, and the typewriter, an office machine that fostered a new skill. In diverse ways, technology entered middle-class ideas of a better life. Neither the colonial state's discourse on "improvements" nor nationalist critiques of industrialization and globalization seemed aware of how readily middle-class and working-class Indians absorbed, used, and modified Western tools and machines. Tailors used the sewing machine to create new fashion styles; bicycles and typewriters were not just tools for the growing urban service industries but also "marked out a role for the innovative . . . mechanisms of pedal, treadle, keyboard, and rotating mill subsequently applied to other mechanical devices."[57] The openness of markets sponsored by the empire played a part.

Medicine is an interesting field. It straddles theory and practice, science and technology, abstract knowledge, and commercial knowledge; because most artisanal knowledge remained tacit, in the 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 formal learning institutions. When this written knowledge encountered European written knowledge, it had a committed following of consumers and practitioners. In turn, Europeans were attracted to Indian theory and practice, which were better equipped to deal with tropical diseases and conditions. As such diseases took an enormous toll on lives, medicine was a productive area for two-way exchange.

The Indian Medical Service was one of the most organized and scientifically competent public health institutions in the tropical world. Research, however, was neither a priority nor always feasible given the limited budget. In addition, the health service remained

[56] Arnold, *Everyday Technology*, 11.
[57] Arnold, *Everyday Technology*, 67.

conservative.[58] In practice, members of the service were applying indigenous diagnostics and organic resources long in use for treating routine diseases. Thus, doctors, scientists, and administrators faced two options for dealing with “alternative” medicine: absorb and recycle tradition, or prioritize knowledge systems, which represented the official stance and drove many patients away from the public health system.

Public health was a serious issue in late nineteenth-century India as a result of devastating famine, followed by cholera, smallpox, and malaria epidemics, as well as the appalling hygiene in port city slums. Port cities had expanded very rapidly, developing two identities, a European quarter and an Indian one. On the Indian side, urban planning and management were ignored, unlike on the European side. Rapid population growth and higher population density in European quarters, however, exposed them to waves of plague epidemics at the turn of the twentieth century. For public health authorities, sanitary engineering and environmental health issues were crucial concerns.[59] Public health drives encountered tension due to Indian patients’ ambiguous attitude and the rivalry between knowledge systems and culturalist claims. There was also a great deal of informal research, learning, reverse engineering, and revaluation of knowledge.[60] None of this research represented either Westernization or localization.

Epidemiology was one field where basic research did happen in India, again owing to the advantage of cross-border movements for scientists. Around 1900, cholera, smallpox, plague, and malaria accounted for 24 out of 40 deaths per 1,000 people in South Asia. If these four diseases did not exist, life spans would have been similar in Britain and India. The plague pandemic at the turn of the century was especially devastating in India. This country was also the source of cholera, which was endemic in cities, market towns, places of pilgrimage, and famine-hit areas.

Dealing with these diseases required a two-part strategy: research on aetiology potentially leading to a vaccine or preventive action, and research on social practices that influenced transmission. Around 1900, India was one of the world’s leading hubs of bacteriological research and attracted some of the best scientists in Europe. Robert Koch did part of his

[58] Harrison, *Public Health*.
[59] Kumar, “Probing History of Medicine.”
[60] Arnold, *Science, Technology and Medicine*; Mukharji, *Nationalizing the Body*; Ramanna, *Western Medicine*. Some bureaucrats believed that India’s problem was its population and advocated birth control technology; Ahluwalia, *Reproductive Restraints*.

cholera study in India. So did the Ukrainian bacteriologist Waldemar Haffkine and Swiss-French scientist Alexandre Yersin. Haffkine developed a cholera vaccine in Bombay, and he developed and then trialed plague vaccines from 1896 to 1902. In a laboratory in south India, Ronald Ross discovered that the malaria parasite lived in the gut of the *Anopheles* mosquito. This was not a one-way exchange of knowledge, as the experts relied on teams of Indian associates. Nitya Gopal Mukherji, a more offbeat individual and student of Louis Pasteur, was possibly the top expert on silkworm diseases at the turn of the century.[61]

Statisticians, doctors, and famine relief officers surveyed affected areas and produced some useful knowledge, as well as some of dubious value. Possibly the first controlled trial (if not randomized) in India was in the Kanthalbagan area of Entally, central Calcutta. Statisticians led these trials and wrote in medical journals. A cholera vaccine trial at Kanthalbagan featured in the 1895 *British Medical Journal*. By 1940, deaths from the four diseases had fallen below 14 per 1,000, marking a great demographic turnaround.

Conclusion

What lessons does this study offer a global history of URK? The India case questions the tendency to identify URK with the emerging "enlightened economy" in Europe. My claim is that URK "allowed for a sustained rise in labor productivity" in India. Major elements in this process of change were the transfer of tools, technologies, and work practices from Britain to India and the fundamental geology, meteorology, and bacteriology research conducted in India.

This history, however, is far from an uncomplicated "diffusion" process. Not everything that was useful in Britain proved to be useful in India. The context shaped the usefulness of the idea, modified the idea or its application mode, and created new challenges. This article presents the differentiated impact of URK on production conditions in India. An investigation into this difference requires considering how the colonial markets and the colonial state impacted production. Conditions changed little in agriculture. Studies argue that the stagnation in agriculture was on account of institutional reforms to meet state revenue objectives but reduced the incentive to invest.[62] However, another geographical factor

[61] Projit Bihari Mukharji, "Fermenting Vernaculars: Pasteur, Putrefaction and Colonial Agro-industries," Annual Meeting of the History of Science Society, Chicago, 2014.
[62] For discussion: Roy, *Economic History of India*.

impacted the challenge of transforming agriculture—an acute seasonal shortage of water was too big a challenge for the state. It needed to raise more money, but the British Indian state had a conservative fiscal stance. The success, albeit costly, of the 1970s Green Revolution, with state support, confirmed that transforming traditional agriculture required combined fiscal and technological intervention.

Services and manufacturing absorbed and reused ideas much more successfully. The railways, the telegraph, and public health had state backing. Textile factories could import a range of packaged and patented Western knowledge, aided by market integration within the empire. Doctors and artisans, who embodied robust knowledge traditions, absorbed global ideas selectively. All these examples had their problems: factories with developing skills, craft factories due to favoring migrant men over women. Standardization and quality control, or how to prove reliability, posed significant challenges. Because sources are limited, we are still far from a conclusive story on these spheres of URK exchange.

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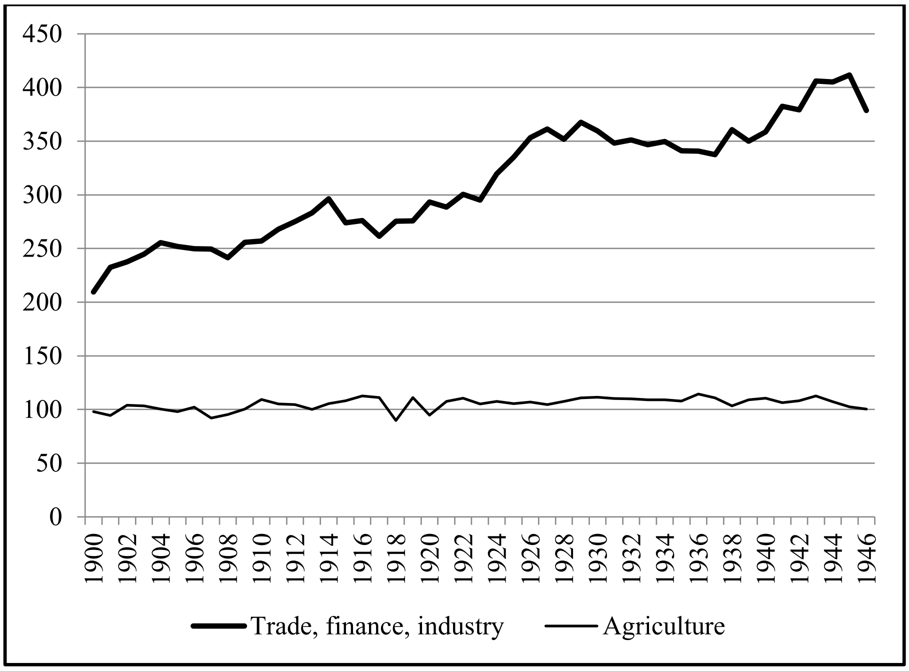

FIG. 1. Evidence of rise in productivity in handmade cloth production (Net output per person, Rs. in 1938–39 prices).

The figures combine British India and the princely states. Agriculture + includes other natural-resource-dependent occupations like fishery and pastoralism. (Adapted from data in Sivasubramonian, *National Income of India*.)

Table 1. Estimates of Physical Productivity in Handloom Weaving, 1901–39.

	Looms (million)	Workers in handloom industry (million)	Cotton Cloth Output (in million lbs of yarn equivalent)	Output per Loom (Index)	Output per Worker (Index)
1901	2.2	3.3	207	100	100
1921	2.0	2.4	235	125	156
1932	2.0	2.1	379	202	288
1939	2.0	n.a.	426	227	n.a.

Notes: From Roy, “Acceptance of Innovation.” Between 1901 and 1939, volume of cloth production in handlooms in India increased substantially, using an almost unchanging number of looms. The numbers reported here exclude Burma.