Roots of Interconnection: Communications, Transportation and Phases of the Industrial Revolution

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Transnational ethical conflicts are more frequent in the contemporary world and because of the greater interconnection among societies. Though scientists and engineers have maintained active contact with colleagues in other countries for centuries, until recent decades such contacts were limited to periods of study at a foreign university, occasional collaboration in labs or on projects, and exchange of research results through publication or presentation at conferences. As societies became more interconnected, the patterns of joint activity deepened. At the same time, the impacts of science and engineering were felt more deeply in society as the connections between basic science on one side and applied science, technology, and engineering of human-made structures became stronger.

Two sets of technological changes increased the possibilities for interconnection between societies by increasing the speed of and broadening access to communications and transportation. The changes in communication took hold more quickly, but both were important to increasing the possibility for interaction among members of different societies.

With invention of the telegraph in the 1840s messages could travel from point-to-point at the speed of shifting electrons rather than of galloping horses or relays of visual signals from tower to tower. Basic transmission time between Paris and London went from days (horses) or hours (visual relay) to minutes. However, the need to receive the messages in a special telegraph office, copy the text onto paper, and then either deliver the paper to the recipient or have the recipient come by to pick it up meant that total message time was longer for anyone who did not have a telegraph office on-site. Initially, telegrams were also expensive enough that their use was limited to government agencies, large business firms, and relatively wealthy individuals. Mass publics began to benefit from telegraphs in the 1860s and 1870s as newspapers expanded their use of telegraphic news services to get stories from distant locales. This roughly coincided with a further expansion of literacy and development (using steam driven presses) of newspapers inexpensive enough for lower middle class, worker, and small farmer households. These developments reinforced one another: without wider literacy fewer people would have an interest in newspapers but without lower prices the newly-literate would have less access to reading material.

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Development of radio in the 1920s and television in the 1950s into mass media meant that audio and visual signals traveling through the air at the speed of sound could spread information to large audiences simultaneously. Governments, broadcasters, and equipment manufacturers all had reason to encourage purchase of radios and televisions, and the cost of basic radios or TVs was soon low enough for most households in industrial countries to have them. The smaller, more portable versions of the 1960s and 1970s made them widely available in developing countries as well. Yet, like newspapers, radio and television broadcasts were one-way media. The publisher or broadcaster could send messages to many people but individual readers, listeners, or viewers could only contact their fellow audience members through face-to-face conversation or the occasional publication of a letter to the editor in the newspaper or the inclusion of listener or watcher comments on the radio or television station.

Telephone services, which first emerged in the late 19th century and expanded considerably after World War I, allowed possessors of telephones to contact each other, but phone service remained fairly expensive,[1] available only to a minority of households even in the industrial countries until after World War II. In many developing countries, access to phone service remained extremely uneven through the 1980s. Only after 1990, as more governments realized the economic importance of extending phone service, and as satellite technology and then cellphones made it possible to connect users without building a nationwide wire network, did differences in access begin to narrow.

Yet, telephones (even cellphones) only link pairs or small groups of users; they do not provide a way for large numbers of people to communicate back and forth simultaneously. Such capability began to develop in the 1990s as the Internet emerged from being a small set of computer connections between specialized users in the USA and Western Europe to the vast world wide web of today. The Internet allows rapid communication among large numbers of users, whether they are accessing someone else's site, running their own site, reading or posting blogs, or interacting on social sites or chat rooms. The Internet has been a great leveler, allowing individuals and small groups the same possibilities of communicating open to governments and other large organizations. Wireless technologies can carry Internet data, though not at quite the same speed as broadband fiberoptic cables, and the same differences in access that affect telephones also affect the Internet.

Even in industrial countries, where Internet access is more widespread than in developing ones, newspapers, radio, and TV coexist with the Internet. Individuals move back and forth among the various media when seeking information. Thus, the older patterns of one-way distribution and of two or small group conversations coexist with the new Internet pattern of multi-party, multiple-direction participation coexist.

These advances in communication have sped up the transmission of new scientific and engineering knowledge, reducing the gap between what is known in the leading laboratories or research centers and what is known elsewhere. Videoconferencing over the telephone network, a merger of telephone and TV technologies made possible by replacement of copper wires with broadband fiberoptic cables, created some possibilities but these facilities were restricted to those who could afford the special equipment required. The addition of webcams to computers opened videoconferencing to anyone with access to the Internet and a computer with video capabilities. These are now sufficiently inexpensive that even households can engage in videoconferencing; small labs, independent inventors, and individual engineers

[1] Particularly long distance service. Correcting prices for inflation by using 1990 dollars, a three-minute call from New York to London cost $244.65 in 1030 and $188.51 in 1940, and $3.32 in 1990. R.J. Herring and R. E. Litan. 1989. *Financial Regulation in the Global Economy* (Washington, DC: Brookings Institution).

can certainly take advantage. The Internet has also changed scientific publishing. It offered the possibility of getting research results out to colleagues and the public more rapidly than was the case with traditional publishing. It also allowed more effective by-passing of peer review systems, with the potential of challenging the whole system. After some initial hesitations, the major journals accommodated the Internet by posting accepted articles online prior to or simultaneously with publication in the traditional hardcopy format and maintaining electronic archives of past issues.

Deeper collaboration among scientists and engineers in different countries was greatly facilitated by changes in transportation technology. In the 18th century a scientist visiting a colleague in another country had to travel overland in a coach, spending nights in Inns (sharing rooms and sometimes even beds with other travelers) and needing days or weeks to get to the destination. Journeys across a body of water required taking passage on a ship. This also involved rather cramped accommodations, but ships could travel more rapidly than coaches, and (seasickness aside) were more comfortable. Thus, scientists who lived in cities close to a port often preferred sea routes. In North America, for instance, more people traveled between Boston and New York by sea than over the always bumpy and sometimes impassibly muddy roads that would be traversed if going by land. Only with construction of a New York to Boston rail line in the 1800s did more people start going by land.

Application of steam technology to transportation in the 19th century increased the speed of travel and increased the size of vehicles, making trips both quicker and more comfortable. Opening of the major interoceanic canals – the Suez Canal in 1869 and the Panama Canal in 1915 – further reduced travel times at sea by replacing the long voyages around the tip of Africa or South America with shortcuts through the Mediterranean or Caribbean. The voyage from England to India, which had taken months in the 18th century, was reduced to weeks in the 19th. The Panama Canal shortened travel between Europe or the east coast of North America to the west coast of South America, or between Asia and the east coast of North America. It had less effect on travel between New York and San Francisco, because the Transcontinental Railroad completed the link between the two in 1867. It was the most dramatic railway project of its time, but was soon followed by other continental-scale efforts as well as further development of shorter railways between major cities. Railroads were the first technology closing the gap in speed between sea and land travel; motor vehicles would do the same, but not until paved highways were constructed in the 1920s and 1930s did motor vehicles become a viable form of long haul transportation.

Trains and steamships, particularly as they became larger and therefore capable of carrying more passengers, reduced the cost of travel to the point that large numbers of students and junior scientists – not just the well-established senior researchers – could afford to go further than immediately neighboring countries. The same increase in the capacity, applied to freight cars and freight-carrying ships, also reduced the cost of transporting goods over long distances, vastly expanding opportunities in international trade. Rather than being confined to relatively light and high-value goods, such as gold, ivory, spices, and porcelain, it was now feasible to ship grain, meat, and a much larger range of raw materials across oceans and continents. Today's long distance food trade is an elaboration on patterns developed in the 19th century, when bulk carriers allowed US and Canadian wheat to be sold in Europe more cheaply than European crops and refrigerator freighters allowed transport of meat (rather than live cattle) from Argentina to Europe.

Transportation speeded up yet again in the 20th century with development of aviation. The true revolution, the opening of air travel to wide sections of the population, came with development of jet aircraft. They

could be made large enough and get from place to place quickly enough to bring the price of air travel down to levels making it available to most of the population in industrial countries and increasing fractions of the population in developing ones. Aviation now does for travel much of what the internet does for communications – make feasible a much thicker set of face to face interactions among participants from all continents.

While these developments in communication and transportation were expanding the possibilities of personal contacts around the world, changes in the patterns of economic activity that they helped encourage were creating a much denser set of economic transactions across national borders. The new communications and transportation technologies were both products of and contributors to the successive phases of the industrial revolution. They were more products of the first phase, the relatively small-scale hit-or-miss changes of the first phase, but contributed to the second, third, and fourth phases.

The first phase of industrial activity emerged in England, then spread to Belgium, the Netherlands, northern France, the northwestern German states, and the USA. In this phase, factories were relatively small and products developed through a process of trial and error in which the proprietor, skilled workman, or more specialized "mechanics" made incremental modifications to machinery, production processes, and product design. In many enterprises, manufacturing remained close to the word's origin a combination of "hand" and "make" because cloth making machinery had to be tended closely and other production depended on considerable adjustment of parts to fit together. In society as a whole, the large numbers of these enterprises shifted the balance between urban and rural areas. In 1760, a bit more than 50% of the male workforce was engaged in farming and 25% in pre-industrial versions of goods production; in 1840 the proportions were reversed. Cities held 21% of the British population in 1760, and 48% in 1840. Though traditional craft production continued in building construction, furniture-making, tailoring, shoe-making, and gunsmithing, centralizing production in a factory with all the machinery run from a central power plant and workers' hours of work, break, and home life determined by the factory whistle characterized the rising textile and iron industries. As new inventions followed, it became possible to produce a widening range of goods – including many that had not existed before – in factories. We are so accustomed to clothing factories today, that our images of clothing production often extend them back to the late 1700s; however, they were not really feasible until invention of sewing machines in the 1850s.

The second phase of industrial activity started in the mid-19th century, primarily in Germany and the USA, and was characterized by three developments: more conscious application of new scientific knowledge to process and product design, greater volume and economy of production through standardized parts and final products, and larger size of factories or other industrial plants. The German dye industry was the first to systematically apply scientific knowledge – in its case chemistry – to the development of new products. The brighter and more stable synthetic dyes it produced soon dominated the market, and synthetic dye manufacturers emerged in other countries as well. Similar efforts to search for and consciously apply relevant basic scientific knowledge also appeared in the steel industry, where chemists were hired to analyze the composition of newly-made steel, identify more reliable ways to eliminate impurities, and even develop new alloys that would strengthen the material, reduce its tendency to rust, or provide other desired characteristics.

The other significant technological development of this period, truly interchangeable parts, was less directly tied to science but did rest on advances in machine making, including use of harder, and therefore, more stable metals in machines. This production process is so familiar to us – it is our basic image of

"manufacturing" – that the difficulty of making component parts to such close tolerances that an assembler can pick up any one of several parts in a bin, insert it in its proper place in the larger product, and be confident that the larger product will work reliably with the technologies of the early 19th century is obscured from view. Part of the reason craft workshops continued to dominate in so many areas was that production involved a lot of trimming and adjusting so parts would work together. Interchangeable parts eliminated that extra work, facilitated repairs, and also allowed using less skilled workers. Fully interchangeable parts were first developed in the USA, so their use was long known as the "American system of manufacturing."

Continuing technological development encouraged growth of larger factories, metal refineries, and textile mills. These larger facilities cost more, transforming the system of financing industry. In Britain and the USA, much of the finance came from factory owners and their friends or associates. In the 1830s the Belgian *Société Générale*, a government-backed investment bank provided much of the capital, and bank finance was so central to German industrialization in the later part of the 19th century that the tradition of including a bank representative on the board of directors became firmly established. The industrial combines (*zaibatsu*) that emerged in Japan in the late 19th century typically included a bank, which was expected to help finance the other affiliated companies when necessary. These differences established an enduring difference in management style between "Anglo-American," "European" (or "continental") and Japanese business management because the first were more accountable to shareholders and the shorter-term time horizons of quarterly reports than the latter two.

Though the first phases of the industrial revolution provided new ranges of goods, many of them remained beyond the reach of the working class. Though controversy about the impact of industrialization on workers and poor farmers continues, there is consensus that these groups did not share much of the gain in national and per capita income. Only with the second phase of the industrial revolution did the position of industrial workers begin to improve, and that was usually the result of government measures, such as Factories Acts regulating hours and conditions of work, wage laws, and government provided social insurance, brought about through pressure from the growing working classes (as in England) or through decisions by governments seeking to reduce support for the more radical socialist and syndicalist movements (as in Germany). A few, like Robert Owen in England and Fourier in France sought to organize industry in a cooperative fashion, but the hierarchical factory remained the main form of industrial organization. Individual manufacturers seeking to sell their goods at a profit had three cost-management strategies available – more efficient use of materials, more efficient production processes, and containing wages – and used all of them in varying degrees. The urge to contain wages was checked by the market in good times because an employer would have to pay attractive wages to recruit and keep workers, but not in bad, leading workers to suffer particularly sharply in economic slowdowns.

Early industrial goods were fairly simple; the buyer could usually evaluate their quality and understand how they worked on his or her own. By 1914, this was becoming less true, the average buyer could understand how electricity worked and what components were required to establish electric lighting, but could not evaluate the quality or safety of the wires and lighting fixtures. The same problem of evaluating quality was even more severe in areas of food and medicine, where the items came pre-packaged and could not be sniffed or tasted before purchase. Thus, buyers had to rely on reputation of the manufacturer, and find some way to distinguish the companies that cut too many corners on quality to compete on price from those that did not. Trademarks became important not just as advertising devices (though they were that) but also as signals to the consumer about the goods. Yet, trademarks were not a complete assurance. Even with the greater understanding germ transmission and good hygiene stemming from advances in

medical sciences, food processing and drug manufacture often involved dangerous practices. As more people came to rely on pre-packaged foods and medicines, as well as on manufactured goods, government safety agencies, independent testing labs, and consumer organizations sought through legal regulations or privately issued standards to assure certain basic safety and quality levels. The challenges of doing so only increased with the later phases of industrialization.
The third phase of industrialization – the conscious combination of highly efficient mass production with mass sales of products – began with Henry Ford's decisions to design an automobile that could be produced at a price within reach of the middle class and to pay his workers a higher than prevailing wage. Though a staunch opponent of labor unions (part of the reason for high wages was to keep unions out of the factories) Ford articulated a vision of an industrial society that used large, highly organized assembly lines to produce a high volume of goods at prices most people could afford. He would make money not by selling some goods having a high profit margin to the wealthier strata but by selling large numbers of goods having a smaller profit margin to almost all. This combination of high production and widespread consumption existed in some areas before Ford, but his tireless advocacy of the idea helped it spread through much of the US economy by 1929 and into some European industries. Even the Soviet government embraced the basic high production/wide consumption idea, though did not put significant efforts into consumer goods production until the 1950s.[2]

By 1900 educated people in all parts of the world regarded industrialization with something they wanted themselves. Yet, countries beginning on the path of industrialization faced significant obstacles because well established firms had the financial resources, physical facilities, and know-how to out-compete newcomers. Industrialists and governments responded to the challenge in various ways. Some sought to develop through collaboration with established firms. Some lobbied for or were offered subsidies and tariff protection by the government. In adopting a Marxist Leninist programs, the Soviet Union took the process even further by establishing central planning and directing a massive industrialization. Russia had begun to industrialize before World War I, but the country was still primarily agrarian and rather backward technologically. The new Bolshevik rulers sought to prove that socialism would be a superior form than capitalism by demonstrating to the world that he determines that central planners could industrialize a country more quickly, more efficiently, and more effectively than in countries where private firms made the economic decisions, while also avoiding the severe exploitation of workers that had marked the earliest phases of Industrial Revolution.

Soviet industrial accomplishments between 1928 and 1940 were considerable and attracted attention around the world. The Soviet Union appeared to have avoided the worst of the great Depression and clearly held off Hitler's legions, so in 1945 its model appeared to be an effective alternative to capitalist industrial development. Simultaneously politicians, intellectuals, and labor movements in Western countries were modifying their own countries' economic organizations. The laissez-faire of the 19th century was replaced by a combination of the welfare state-- that is, using tax revenues and government programs of health insurance, old age pension, and unemployment compensation to provide everyone with a basic minimum standard of living – with a mixed economy – one in which the "key" industrial sectors would be operated by state-owned enterprises while others were left in private hands. The state-owned enterprises were expected to be models of good industrial relations between management and labor while providing society as a whole with goods and services at more reasonable cost because they would not insist on as

[2] Even Marxist economists joined the analytical homage that refers to the mass production-mass consumption scheme of economic organization as "Fordism."

high a profit margin as private investors and owners. In sum, whether led by a center party, a labor Party or a social democratic party, Western European countries transformed themselves into mixed economies that they hoped would combine the advantages of planning with private initiative while avoiding their disadvantages. Individually or together Soviet and Western European influences inspired governments of Latin America, Africa, the Middle East, and Asia to adopt similar systems in the expectation that they, too, could achieve rapid industrialization and allow their populations to enjoy the same material comforts enjoyed in the industrial West.

If the character of industry had remained what it was in 1945, a combination of mass production and mass consumption of goods based on late 19th and early 20th-century technologies, these centralized designs for catch-up would have been reasonably successful if competently administered. Administrative competence varied considerably, but an equally important factor in frustrating the plans – more important than the continued advantages help by established industries in global competition – was the transition to a fourth phase of industry. This phase consisted of massive change in the organization of service provision, office activity, and production brought about by the computer revolution. It started slowly in the late 1970s as computers became cheap enough for larger business firms to use on a regular basis, but gathered speed as the price and capacity of small computers continued down and dominated the economic scene by the mid 1990s.

In production, computer technologies allowed more precise machining or molding of parts as computer-driven robots replaced human operators; they also permitted shifting from long assembly lines making exact copies of one product to shorter production runs in which products could be differentiated by inclusion of different sub-assemblies or components or different casings. The initial result was "batch production," assembly of sets of differentiated versions; the ultimate result was individualized assembly with each order given an assembly ticket and the parts tracked by bar codes. Though dreams of the "paperless office" have not yet been realized, computer-based systems do permit maintaining and using richer databases about customers, clients, and their likely needs.

In the 1980s, these new production and office systems were available only to fairly large firms because computers were expensive. As computer capacity increased and computer costs decreased, medium-sized and small firms were also able to take advantage of the new production and data management technologies. To do so, however, firms needed to have room to experiment. It is telling that Soviet analysts had some of the best insights into the likely consequences of what they called the "scientific-technological revolution" computers were producing, but the Soviet economy was unable to incorporate computer technology effectively. Some of the problem was political – the Soviet government was worried about letting people connect up and communicate through computers – but much of it was organizational. Companies in the West and the developing world also had trouble adjusting, and many once-famous firms disappeared because they could not make the transition.

The same changes in the relation between science and industry extended into the relation between science and warfare. The search for better weapons, tactics, and strategies in war is almost as old as war itself, and often attracted the best minds of the time. Until the 19th century, weapons development relied primarily on trial and error, typically featuring incremental changes except when a new type of weapon was introduced. Tactics and strategy, being matters of organization rather than making physical objects, could and often did feature larger change.

Development of industrial technologies for manufacturing, communications, and transportation transformed warfare in the 19th century. Canning of food (perfected during the Napoleonic Wars) and factory manufacture of weapons and equipment permitted supporting larger armies in the field, while the wealth generated by industrial activity expanded national tax bases sufficiently to support those forces. Steamships increased the speed, size, and gun-carrying capacity of warships while shifting naval concern from dependence on the winds to dependence on fuels and refueling stations. Railways permitted moving troops much more quickly, and armies soon learned to replace the physical conditioning once provided on the march with increased physical activity during training and drill.

The link between advances in basic science and development of new industrial technologies was extended to military technologies as well. Military medical units and individual weapons-makers were already drawing on scientific knowledge in the late 19th century, but this depended largely on decisions by individual units or firms. Systematic efforts by military high commands or high officials of defense ministries to coordinate use of scientific talent in development of weapons and equipment first appeared during World War I. Most of these efforts were wound up in 1918-19, and had to be reestablished in the mid-late 1930s as a new world war appeared more and more likely. Onset of the Cold War competition meant there was no comparable winding-up after 1945; rather, the existing military-science-industry connections were intensified in all the major military powers. The rush to develop nuclear weapons, which absorbed considerable resources in the USA, Britain, Germany, the USSR, and Japan alike, was not the harbinger of a new relation between science and military technology, though it did reveal more clearly than any other 20th century development, the vast capacities for destruction being developed as countries engaged in "total war" bringing their full productive capacities to bear in supporting vast armies and far-flung campaigns.

Military establishments were quick to realize the relevance of computers and information technology in planning, intelligence gathering and analysis, maintenance of command and communication, and locating enemies on the battlefield. Several information technologies, including early versions of the internet, satellite-based remote sensing systems, and satellite navigation systems, were developed for military use and then extended into civilian applications. Like society in general, militaries around the world face the challenges of effectively absorbing rapidly changing computer and information technologies.

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