Chapter 6
History of Technology

Technological change is a key issue for the philosophy of history, because technology is itself a complex social process, involving the influence of many social factors (economic, scientific, political, organizational, educational). So arriving at a history of a particular technology—e.g., electric power, inertial navigation, or medieval ship construction—is itself a challenging and important task for historians. And second, technological change is itself often invoked as one of the large causal factors that account for other important large social outcomes—e.g., population increase, the incidence of war and peace, or environmental change. We need to be able to provide an account of the metaphysics of the causal properties allegedly possessed by technology systems. It is worthwhile to examine both sets of problems in the context of the philosophy of history.

Let us canvass, to start, how the history of technology intersects with meso-history. It does so in several ways:

- Technology constitutes a large "structural force or condition" commonly invoked in macro-historical accounts (e.g., Lynn White's analysis of the stirrup (White, 1962) or Marc Bloch's analysis of the wheeled plough (Bloch, 1966)).
- Technological change is itself a complex historical process, invoking other large-scale structural factors, such as population, education, market circumstances (e.g., Ester Boserup's argument that technological change derives from rising population density and consequent pressure on natural and biological resources; Boserup, 1981).
- A technology is embedded in a specific set of educational, research, and financial institutions that significantly influence the pace and direction of technology change.
- Technological changes are often said to have important meso-level social consequences, distinct from their primary purposes (e.g., extension of a transport technology into new periurban areas may stimulate a distinctive pattern of population growth and settlement patterns; Warner, 1969; Skinner, 1964).

Some historians imagine that new technologies force other kinds of social changes, or even that a given technology creates a more or less inevitable process of development in society. Marx is sometimes thought to offer such a theory, for

D. Little, *New Contributions to the Philosophy of History*, Methodos Series 6,
DOI 10.1007/978-90-481-9410-0_6, © Springer Science+Business Media B.V. 2010

example, when he holds that the forces of production create changes in the relations of production. This view is referred to as technological determinism (Boserup, 1981; Smith and Marx, 1994). The reasoning underlying this interpretation of history goes something like this. A new technology creates a set of accessible new possibilities for achieving new forms of value: new products, more productive farming techniques, or new ways of satisfying common human needs. Once the technology exists, agents or organizations in society will recognize those new opportunities and will attempt to take advantage of them by investing in the technology and developing it more fully. Some of these attempts will fail, but others will succeed. So over time, the inherent potential of the technology will be realized; the technology will be fully exploited and utilized. And, often enough, the technology will both require and force a new set of social institutions to permit its full utilization; here again, agents will recognize opportunities for gain in the creation of social innovations, and will work towards implementing these social changes.

Even cursory examination of current work in the history of technology refutes this idea. All major technologies demonstrate deep contingencies when we examine their development in detail. Why do we have alternating current rather than direct current in the outlets in our homes today? Because Thomas Edison mounted a major public relations campaign involving the eloctrocution of cats in order to defeat the advocates of direct current. There are many examples of potentially productive technologies that failed to come to full development after discovery (for example, the water mill in the ancient world and the Dvorak keyboard in the contemporary world). There is nothing inevitable about the way in which a technology will develop—imposed, perhaps, by the underlying scientific realities of the technology; and there are numerous illustrations of a more complex back-and-forth between social conditions and the development of a technology. And we have numerous examples of contingent and unexpected social consequences emerging from the advent of a major new technology. So technological determinism is no more persuasive than any other mono-causal theory of historical change.

Rather, it is more credible to regard technology as one among a number of meso-level social factors that influence historical development at a given time. We are well advised to approach the history of technology with the ideas of contingency and conjunction in mind: historical outcomes are almost always the result of multiple sets of conjunctural causes, and the results are highly contingent and path-dependent.

For more credible interpretations of the relationships that exist between technology and historical change, we can consider the work of some very insightful historians.

6.1 History of Electric Power

Let us examine an important detailed study in the history of technology: Thomas Hughes's groundbreaking book, *Networks of Power: Electrification in Western*

Society, 1880–1930 (Hughes, 1983).[1] Hughes has done much in the past 30 years to provide a new foundation for the history of technology, and this work on the history of electric power is among his most important contributions. Hughes constructs a complex narrative that leads from the important scientific discoveries and inventions in the 1880s which created the possibility of using electricity for power and light; through the creation of complex organizations by such systems builders as Thomas Edison and Elmer Sprague to solve the many technical problems which stood in the way of successful implementation of these technical possibilities; to the establishment of even larger social, political, and financial systems through which systems builders implemented the legal, financial, and physical infrastructure through which electricity could be adopted by large cities and regions.

Along the way Hughes demolishes several important misconceptions about the history of technology. He refutes, first, the notion that there was an *inevitable logic* to the development of electric power. At various points in the story he tells, there are choices available that do not have unique technical solutions. The battle of the systems (direct versus alternating current) is one such example; Edison's work proceeded on the basis of a technology of direct current, whereas the industry eventually adopted the technology of alternating current. Each choice posed technical hurdles that required solution; but there is good reason to believe that the alternative not taken could have been adopted with suitable breakthroughs along the other path. The path chosen depends on a set of social factors—popular opinion, the press, the orientation of professional engineering schools, the availability of financing, and the intensity of intellectual resources brought to bear on the technical problems that arise by the research community.

Second, Hughes establishes that, even when the basic technology was settled, the *social implementation of the technology*, including the nature and pace of adoption, was profoundly influenced by non-technical factors. Most graphically, by comparing the proliferation of power stations and power grids in London, Paris, and Chicago, Hughes demonstrates that differences in political structure (e.g. jurisdiction and local autonomy) and differences in cultural attitudes elicited markedly different patterns of implementation. Chicago shows a pattern of a few large power stations in the central city; London shows a pattern of myriad small stations throughout the metropolitan area; and Paris shows a pattern of a few large stations along the Seine in the periurban areas of the city. Moreover, these differences in styles of implementation can have major differences in other sorts of social outcomes; for example, the failure of London to implement a large-scale and rational system of electric power distribution meant that its industrial development was impeded; whereas Chicago's industrial output increased rapidly during the same time period. These patterns of build-out, and the urban geography that they helped to create, were the effect of

[1] The history of technology as a discipline has been particularly fruitful in the past 20 years. Historians in this field have moved substantially beyond the conception of technological change as a series of stages of technical design and implementation, to focus on the social constitution of the process of technological change. Thomas Hughes has played a central role in this revival, as has the journal *Technology and Culture*.

social and political factors at the level of municipal government, regional financial institutions, and the like.

Third, Hughes sheds light on the social and individual characteristics of *invention and refinement* that occur internal to the process of technological change. He describes a world of inventors and businesses that was highly attuned to the current challenges that stood in the way of further progress for the technology at any given time. Major hurdles to further development constituted "reverse salients" which then received extensive attention from researchers, inventors, and businesses. The designs of generators, dynamos, transformers, light bulbs, and motors each presented critical, difficult problems that stood in the way of the next step; and the concentrated but independent energies of many inventors and scientists led frequently to independent and simultaneous solutions to these problems.

Fourth, Hughes makes the point that, in the instance of this technology at least, the development of the technology was inseparable from the establishment of "massive, extensive, vertically *integrated production systems*," including banks, factories, and electric power companies (Hughes, 1983, p. 5). "The rationale for undertaking this study of electric power systems was the assumption that the history of all large-scale technology—not only power systems—can be studied effectively as a history of systems" (p. 7). The technology does not drive itself; and it is not driven (exclusively) by the technical discoveries of the inventor and scientist. Rather, the eventual course of development and implementation is the complex result of social pulls and constraints, as well as the inherent possibilities of the scientific and technical material.

Finally, Hughes introduces the important concept of "*technological momentum*". By this concept he means to identify the point that a large technology—transportation, communication, power production—once implemented on a wide scale, acquires an inertia that is difficult to displace. Engineers and designers have acquired specialized knowledge and ways of approaching problems in the field; factories have been established to build the specialized machines and parts needed for the technology; and investors and banks have embedded their fortunes in the physical implementation of the technology. "Business concerns, government agencies, professional societies, educational institutions, and other organizations that shape and are shaped by the technical core of the system also add to the momentum" (p. 15).

Hughes demonstrates several important lessons for large-scale historical explanation. First, through his detailed account of a complex 50-year international process of design and implementation, he shows that large-scale events can be explained, and that a variety of large-scale structural factors are pertinent to the outcomes. Second, he demonstrates the important scope of agency and choice within this story. Outcomes are contingent, and individuals and local agents are able to influence the stream of events at every point. And finally, through his concept of technological momentum he provides a constructive way of thinking about the social influence of technology itself within the fabric of historical change—not as an ultimate determinant of outcomes, but as constraining and impelling set of limitations and opportunities within the context of which individuals strategize and choose.

6.2 Alternative Forms of Industrial Organization

Turn now to a second important example of contemporary meso-history relevant to technology change: research by Charles Sabel and others on alternative modes of industrial organization in European economic history. There is a conventional line of thought in economic history that emphasizes the inevitability of certain broad characteristics of economic change and institutional organization in any pre-modern economy.[2] It is the familiar storyline of industrial revolution in Western Europe. Rising agricultural productivity stimulated population growth and permitted the increase of non-agricultural population. Demand for consumption goods increased as a result of this population increase—leading to rising prices for common consumption goods. These price changes stimulated more extensive production for the market; they also created an incentive for technological innovation (resulting in rising productivity of labor). Machine production was a predictable response to these commercial and financial changes, eliciting innovations in power technology and leading to an increase in the scale of production (from workshop to factory). Factory production elicits greater technological innovation, greater division of labor, and a rising capital-labor ratio; these changes in turn require expansion in the scope of production. Mass production based on low-skill labor, extensive use of specialized machines, and extensive use of non-biological sources of power follow.[3] This is the narrative of Marx's *Capital* (Marx, 1977), and also underlies the Fordist interpretation of the American industrial system.

However, recent work in economic history suggests strongly that this story is significantly too inevitabilist. Population, prices, and technology are all highly pertinent to the economic pathway experienced by Western Europe; but they do not determine either the institutions through which economic activity takes place or the outcome of economic development. And the stylized history of Western Europe's economic transformation that the story represents is deficient in failing to recognize the very great degree of variation there was in basic economic institutional arrangements. Contingency rather than necessity, and diversity rather than uniformity, appear to be the dominant features of much recent economic history—even in Europe and North America.

In "Historical Alternatives to Mass Production" Sabel and Zeitlin (1985) argue against the idea of the historical inevitability of mass manufacture, both theoretically and empirically. They argue that historically feasible alternatives exist—in particular, the alternative of flexible production, short runs, specialized products, flexible machinery, and skilled artisanal and engineering labor. The argument in this essay is

[2]There has been lively work on the issue of the nature and causes of economic development in the early modern European economy in the past 20 years. Especially central is the question of the causal origins of self-sustaining growth in the early modern period of European development. Early expressions of work in this area include Deane (1979), Feinstein (1981), Deane and Cole (1967), and Postan (1972). Important contributions to the more recent literature include Crafts (1985), Jones (1988), Floud and McCloskey, (1981), and O'Brien and Keyder (1978).

[3]Deane and Cole (1967) provide a representative narrative along these lines.

that political and class factors produced the imperative toward mass manufacture—not the technical characteristics of new technologies, or the efficiencies and cost structures of the various alternatives. Mass production techniques in textiles spelled the doom of the weavers in the 1820s; this is an instance of a clear efficiency-based explanation for the dominance of one system over another. But there were historically feasible alternatives to factory production in many industries—glass, silk, watches, metal working, machine goods—where skilled artisanal production could have successfully competed with techniques of mass manufacturing. In *Worlds of Possibility* (1997) they expand this point by demonstrating even broader "strategic" variability within existing forms of industrial organization—substantial levels of hedging on the part of managers, and substantial effort to influence the competitive environment. And in fact, Philip Scranton demonstrates that much of the history of American factory manufacturing took the form of "flexible manufacturing" rather than mass manufacturing through at least the 1960s (Scranton, 1997). Locomotives, specialized metal-working tools, jewellery, and furniture all were produced in factories involving skilled labor, flexible manufacturing, and batch industrial processes.

Sabel and Zeitlin, then, emphasize contingency and agency within the process of technology development, economic growth, and institution-building: there were historically feasible alternatives in the organization of production with modern technologies; and in fact, managers, workers, and planners exploited these contingencies so that the alternative forms in fact prospered in various settings. They emphatically contest the sense of iron necessity in outcomes of economic processes, relative to the standard approach to the history of industrialization of Europe and America.

Sabel and Zeitlin's case is important for several reasons. First, it offers a striking and persuasive alternative to the standard view of European economic history—that traditional techniques of production and modes of economic organization based on skilled labor, small manufacture, and traditional techniques, were inevitably replaced by factory production, the application of specialized tools and machinery, and the de-skilling of industrial labor. Proletarians replaced artisans, and factories replaced specialized shops. And second, more generically, it significantly challenges a dominant paradigm of understanding large-scale historical change—as a cumulative and sweeping process through which one form comprehensively replaces another, based on the technical or economic superiority of the successor. Sabel and Zeitlin argue instead for a conception of social change that emphasizes flexibility and multiplicity of forms—factories, specialized machine shops, large-scale rigid units and small, flexible operations—governed by strategic decision-makers who deliberately chose a range of options well-designed to secure their interests. At any given time, a number of alternative economic institutions are in use (types of firms, for example, with types of technology and forms of labor skill), and very significantly different forms may be viable simultaneously and indefinitely. An ecological metaphor, in which many different organisms exploit different niches within one environment, fits this picture better than the notion of economic competition and the inevitable success of one particular type. This portrait is important, because it may lead us to doubt, or at least inspect with newly critical eyes, the blanket statements that we sometimes find about "feudal institutions" or "traditional agriculture" or "early capitalism."

The detailed scrutiny of these forms of contingency and diversity within European economic history is highly productive. It leads us to recognize the multiplicity of forms of adaptation that are available in many historical cases; and at the same time, it serves to identify some of the structural factors that impel the process of change in one direction rather than another.

6.3 Railroads as a Historical Cause

The development of the railroad was a transformative technology in the nineteenth century. Here at least one might wish to argue that the development of the technology was inevitable, and its effects on social organization were predictable. However, neither of these assumptions is correct. There were many branching possibilities in the development of the technology itself; and historians and social scientists have demonstrated that the transportation potential represented by the technology had rather different effects on the social geography of different countries as they developed their rail networks.

An important example of a study of the social-technological development of the railroad is offered in William Cronon's fascinating history of *Chicago, Nature's Metropolis: Chicago and the Great West* (Cronon, 1991). Cronon tracks the effects that the extension of the rail network had on the city of Chicago and the region surrounding it into Illinois, Wisconsin, Iowa, and Michigan. Cheap, reliable rail transport between Chicago and New York created large markets for grain and beef. This gave incentives to farmers and traders to organize their activities in such a way as to take advantage of the profits newly available in these markets. But Cronon points out that transportation by railroad of large volumes of grain required a reorganization of the market institutions that were used: the establishment of grain elevators along the rail lines, the establishment of a grading system for qualities of grain being sold by farmers to elevator operators, and the establishment of a futures market for grain and beef. And he observes that entrepreneurs recognized the gains that could be achieved by developing these institutions and carried them forward. So the technology "needed" a reorganization of the market for grain; entrepreneurs recognized an opportunity for profits in achieving this reorganization; and the necessary social innovations occurred.

The central causal mechanisms in this instance are the market demand created by rising population in the Northeastern United States (Boston and New York), and Chicago's favorable location for rail and water transport to points east. Concentrated urban demand causes development of infrastructure and flow of timber and grain. Residents in the urban eastern United States need food, so rising population creates rising demand for grain. Rising demand gives economic incentive to distant producers to increase production. And it gives economic incentives to commercial agents to organize infrastructure (warehouses, railyards, grain elevators, exchanges) that permit efficient and large-scale trade in grain. Goods need to be transported from the point of production to the point of consumption—thereby creating an economic incentive for transport providers to establish transportation infrastructure (railroads, terminals, rolling stock). Greater availability of goods transported by effective transportation, in turn, provides incentive to new residents and traders to choose Chicago over Peoria—leading in turn to rising population and consequent demand.

It is worth noting that the processes described here have, in turn, additional unintended and unexpected consequences. Dense population causes more frequent public health problems. Effective transportation systems create constituencies of working class people who can be mobilized to politics and union activity (e.g. the Pullman strike). More intensive inter-regional transportation can have the effect of spreading disease more rapidly. Effective communication systems cause the more rapid diffusion of ideas, innovations, and social movements—which in turn cause changes in technology, politics, and patterns of consumption.

In analyzing and viewing the development of great metropolitan regions—the restructuring of economic activity throughout the region (crops, forestry, manufacturing, the movement and circulation of people and goods, the proliferation of new and more diverse and specialized enterprises)—we see a great and powerful process. We see the invention of new inter-locking business institutions and practices; new patterns of consumption; and new secondary technologies that fill the niches created by the new regional flows.

Thus transport technology innovation plays a key role in these patterns of regional development. So a major technology plays an important causal role in historical outcomes. But is it an instigating cause; an important explanatory variable; or a predictable and obvious necessary condition (and therefore not of special explanatory interest)? We might say that it is the economic causes—population, demand, and markets—that elicit the innovations and adoptions of the new technology and that transport is simply an intervening variable. It seems clear from Cronon's account that rail transport played a somewhat autonomous causal role in the process. If the investments had not been made in Chicago's rail infrastructure; if siting decisions had been made differently crossing the Midwest; and if supporting innovations (futures grain markets, grain elevators) had not been forthcoming, then Chicago's economic and social development would have been very different.

We can also ask the question of contingency in the Chicago story. How much path-dependency do we find in this story? Was it the circumstances of the location of the terminus and the initial structure of the network that led to the development of the metropolis? Or were the circumstances of pre-existing water transport (Great Lakes), along with geography linking east and west, sufficient to select Chicago over other possible hubs? This appears not to be the case; there were other important cities that had the same strategic opportunity of water transport in the Great Lakes (Milwaukee, Toledo, Cleveland). So Chicago's emergence as the premier city of the region was a contingent event.

Might we imagine that Chicago's pre-eminence was established once the rail system arrived? Was the business and ecological transformation of Chicago's region sound inevitable, given the extension of the rail system into Chicago? Once again, contingency comes into the story. The build-out of the American rail network was itself a highly contingent matter; the major east–west lines could have been placed in numerous alternative routes, including a network that would have made St. Louis the major rail nexus in the center of the country. Second, the policy environment within which the American rail network developed represented another major form of contingency. As Frank Dobbin demonstrates, England, France, and the United States possessed very different "policy cultures", and these differences created substantial differences in the way in which the basic technology of the railroad was exploited in the three national settings (Dobbin, 1994). And third, there are multiple social solutions that would work roughly as well as the institutions of the grain elevator and the futures market for solving the business challenges of mass transport and marketing of grain. The solutions that emerged in Chicago were therefore contingent as well.

Let's consider more closely one aspect of this historical contingency: Frank Dobbin's analysis of the historical processes associated with the extension of railroad technology in different settings (Dobbin, 1994). Dobbin's research is intended to address a relatively limited historical puzzle. A powerful new technology, the railroad, was developed in the first part of the nineteenth century. The nature and characteristics of the technology were essentially homogeneous across the national settings in which it appeared in Europe and North America. However, it was introduced and built out in three countries—the United States, Britain, and France—in markedly different ways. The ways in which the railroads and their technologies were regulated and encouraged were very different in the three countries, and the eventual rail networks had very different properties in the three countries. The question for explanation is this: can we explain the differences in these three national experiences on the basis of some small set of structural or cultural differences that existed among the three countries and that causally explain the resulting differences in build-out, structure, and technical frameworks? Or, possibly, are the three historical experiences different simply because of the occurrence of a large but cumulative number of unimportant and non-systemic events?

Dobbin attempts to explain these differences in implementation as a consequences of differences in what he calls "policy culture" in the three countries. He argues that there were significantly different cultures of political and industrial policy in the three countries that led to substantial differences in the ways in which government and business interacted in the development of the railroads. "Each Western nation-state developed a distinct strategy for governing industry" (Dobbin, 1994, p. 1). The laissez-faire culture of the United States permitted a few large railroad magnates and corporations to make the crucial decisions about technology, standards, and routes that would govern the development of the rail system. The regulated market culture of Great Britain favored smaller companies and strove to prevent the emergence of a small number of oligopolistic rail companies. And the technocratic civil-service culture of France gave a great deal of power to the engineers and civil servants who were charged to make decisions about technology choice, routes, and standards.

These differences led to systemic differences in the historical implementation of the railroads, the rail networks that were developed, and the regulatory regimes that surrounded them. The US rail network developed as the result of competition among a small number of rail magnates for the most profitable routes. This turned out to favor a few east–west trunk lines connecting urban centers, including New York, Boston, Chicago, and San Francisco. The British rail network gave more influence to municipalities who demanded service; as a result, the network that developed was a more distributed one across a larger number of cities. And the French rail network was rationally designed to conform to the economic and military needs of the French state, with a system of rail routes that largely centered on Paris.

This example illustrates the insights that can be distilled from comparative historical sociology. Dobbin takes a single technology and documents a range of outcomes in the ways in which the technology is built out into a national system. And he attempts to isolate the differences in structures and cultures in the three settings that would account for the differences in outcomes. He offers a causal analysis of the development of the technology in the three settings, demonstrating how the mechanism of policy culture imposes effects on the development of the technology. The inherent possibilities represented by the technology intersect with the economic circumstances and the policy cultures of the three national settings, and the result is a set of differentiated organizations and outcomes in the three countries. The analysis provides abundant documentation of the social mechanisms through which policy culture influenced technology development; the logic of his analysis is more akin to process tracing than to the methods of difference and similarity in Mill's methods.

The research establishes several important things. First, it refutes any sort of technological determinism, according to which the technical characteristics of the technology determine the way it will be implemented. To the contrary, Dobbin's work demonstrates the very great degree of contingency that existed in the social implementation of the railroad. Second, it makes a strong case for the idea that an element of culture—the framework of assumptions, precedents, and institutions defining the "policy culture" of a country—can have a very strong effect on the development of large social institutions. Dobbin emphasizes the role that things like traditions, customs, and legacies play in the unfolding of important historical developments. And finally, the work makes it clear that these highly contingent pathways of development nonetheless admit of explanation. We can identify the mechanisms and local circumstances that led, in one instance, to a large number of firms and hubs and in the other, a small number of firms and trunk lines.

Cronon and Dobbin illustrate several different aspects of technological causes and technological contingency in their accounts of the railroad. Their work illustrates several fundamental points about the role of technology in historical change. A new technology creates new opportunities for power, wealth, efficiency, or productivity; so a new technology can be a powerful force for social and economic change. Governments, farmers, entrepreneurs, and corporations have a complicated set of incentives that lead them to consider developing the new technology. So new technologies certainly function as effective historical causes. The development of a technology, however, introduces deeply significant elements of contingency. The term "path-dependency" is an accurate description of the process of the development of a major technology. Third, a technology is both influenced by social factors in the society in which it is developed, and also influences the future direction of social factors in the society. Thus technology is both cause and effect of social change. And, finally, it is evident that the study of the history of technology is inevitably a study of social processes and institutions as much as it is a study of machines and inventions. Technology is a social product, shaped by the needs and powers that exist in society as much as it is shaped by scientific imagination and discovery.

6.4 Water Transport in China

Water transport was a crucial factor in China's economic and spatial development. Many parts of China were very richly provided with networks of rivers; these were supplemented by canals to provide low-cost transport throughout relatively large spaces. And China's major rivers provided the possibility of long-distance commerce based on low-cost river transport. Water transport, according to G. William Skinner, established the structure within which "macro-regional" economies emerged; and the social transactions and behavior of people throughout China were very much structured by these economic networks (Skinner, 1964, 1977b). The role of transport in late Imperial China was thus of great importance for the development of the size and spatial distribution of population, the reach of the state, and the ability of the state to maintain social order. The grain trade provided for more intensive population development, the movement of troops helped to secure public order, and the movement of officials and messengers was essential to the imperial state's ability to impose its will on the periphery.

Skinner's insights have generated a very fertile program of research for the China field. His own analysis of the marketing hierarchies of pre-modern China sets the social context for much of the subsequent study that scholars have provided for subjects as diverse as urbanization, religion, and rebellion.

Winston Hsieh (Hsieh, 1978) provides an interesting example of how these factors come together in explanation of an important historical episode—the rapid and patterned diffusion of rebellion in the Canton Delta in 1911. His narrative depends on transport in several important ways. The population density of the lower Canton Delta was made possible by the availability of low cost bulk transport through the water network of the delta. This permitted farmers to specialize in export rice; commercialization proceeded intensely, and the population density of the region rose sharply. Another important effect occurred in the small city of Shih-Ch'i; its western districts grew rapidly in urban intensity in the final decades of the nineteenth century, while the other parts of the city declined. Hsieh attributes this pattern of growth to the importance of ferry and steam shipping on the Shih-ch'i Sea (Hsieh, 1978, p. 129). But the income created by low-cost transport was challenged by another transportation innovation—the establishment of the Canton-Kowloon railroad in

1906, which allowed rice merchants to bring Thai rice directly into competition with the rice harvest of the lower Canton delta.

Hsieh argues that transport and marketing hierarchies provide critical explanatory variables for the timing and pattern of mobilization of Republican rebellion in the Canton Delta in 1911. Transport constituted a longstanding structural variable that created population density and population interests that were vulnerable to crisis—and therefore provided a population ready to be mobilized when crisis hit. And the marketing routes that had been established through local markets also provided the networks through which agents of mobilization—sectarians, martial arts instructors, millenarianists—would travel and mobilize.

6.5 Agriculture and the Natural Environment

Consider now another large example of meso-history with a technological core. In this case the subject has to do with the relationship between agriculture (a fundamental human technology) and the natural environment. (Population growth comes into the story as well; expansion of agricultural capacity permitted expansion of China's population.) Mark Elvin's title*, The Retreat of the Elephants: An Environmental History of China*, is brilliantly chosen to epitomize his subject: the human causes of longterm environmental change in China over a 4000 year period of history (Elvin, 2004). How many of us would have guessed that elephants once ranged across almost all of China, as far to the northeast as what is now Beijing? And what was the cause of this great retreat? According to Elvin, it was the relentless spread of agriculture and human settlement.

In other words, human activity in farming and water management changed the physical environment of China in such a profound way as to refigure the range and habitat of the elephant. "Chinese farmers and elephants do not mix." This story provides an expressive metaphor for the larger interpretation of environmental history that Elvin offers: that environmental history is as much a subject of social history as it is a chronology of physical and natural changes. Human beings transform their environments—often profoundly and at great cost.

This analysis complements some of Elvin's arguments in "The High-Level Equilibrium Trap"—the idea that Chinese agriculture had reached a stage of development by the late imperial period in which technique had been refined to the maximum possible within traditional technologies, and population had increased to the point where the agricultural system was only marginally able to feed the population (Elvin, 1972). So further productivity advances were impossible; the technology had been finetuned to the point that only advanced scientific research could further increase grain productivity. This is what he refers to as a "high-level equilibrium trap." He returns to something rather similar to this idea in *Retreat of the Elephants* by offering a theory of environmental exhaustion ("Concluding Remarks"): a measure of the degree to which population increase and economic growth have placed greater and greater pressure on non-renewable resources.

This is now a familiar story, when we consider the anthropogenic influences on global warming in the past 50 years. What Elvin's book demonstrates is that human activity is an integral part of the story in the long sweep of history as well. Nowhere is this fact more evident than in Elvin's treatment of the perennial problem of water management in China. Seawalls, canals, dikes, drainage, irrigation, desalinization, and reservoirs were all a part of China's centuries-long efforts at water control. And each of these measures had effects that refigured the next period in the water system—the course of a river, the degree of silting of a harbor, the diminishment of a lake as a result of encroachment. (Peter Perdue tells a similar story about the fortunes of Hunan's Dongting Lake (Perdue, 1987); the lake's boundaries shrink as opportunistic farmers fill it in.) The waterscape of late Imperial China was very much a moving picture as human activity, deliberate policies, technology innovations, and hydrology and climate interacted. There is a particular drama in seeing a centuries-long history of magistrates attempting to control the hydrology of the great rivers and deltas of the Yangzi and Yellow Rivers, to counteract silting and flooding and the massive problems that these processes entailed. Here the local officials made their best efforts to absorb the history of past interventions and their effects in order to design new systems that would obviate silting and flooding. This required planning and scientific-technical reasoning (Elvin, 2004, p. 137); it required large financial resources; and, most importantly, it required the mobilization of vast amounts of human labor to build dikes and polders. But always, in the end, the water prevailed.

Elvin's history is fascinating in a number of ways. He is an innovative writer of history, bringing new materials and new topics into Chinese historical research. His interweaving of agriculture, population growth, technology, and environmental change is masterful. He combines economic history, cultural history, and natural history in ways that bring continual new flashes of insight. He makes innovative use of literature and poetry to try to get some inklings into the attitudes and values that Chinese people brought to the environment. And he returns frequently to the dialectic of population growth and resource use—a rising tempo of change that imposes more and more pressure on the natural environment.

6.6 Warfare: The Franco-Prussian War

When we consider the role of technology in history, we are brought to consider some of the basics of human civilization: farming, control of the natural environment, transportation, manufacturing. But warfare and the technologies associated with largescale violence are also largescale historical factors. So let us now consider an example drawn from recent French history: the defeat of France in the Franco-Prussian War in 1870. This is an episode that is often explained in terms of technology (railroads and armaments); but, as we will see, the situation was more complex.

The rapid, bloody, and total defeat of the French army by the Prussian army in 1870–1871 was an enormous and unexpected shock to France and to Europe.

Since the Napoleonic Wars it was taken as given that France's armies were powerful, well-equipped, and well generaled. But the Prussian army quickly defeated French armies across eastern France, from Wissembourg to Sedan, with massive loss of life on the French side. And the collapse of the army was rapidly followed by the siege of Paris and the Paris uprising leading to the establishment of the Commune of Paris and eventually its bloody suppression. So this period of 2 years was a critical moment in France's history in the nineteenth century. Michael Howard's 1961 history*, The Franco-Prussian War: The German Invasion of France 1870–1871* (Howard, 1961), is probably the most comprehensive book in English on the Franco-Prussian War. Here is how Howard expresses the comprehensiveness and shocking totality of France's defeat:

> The collapse at Sedan, like that of the Prussians at Jena sixty-four years earlier, was the result not simply of faulty command but of a faulty military system; and the military system of a nation is not an independent section of the social system but an aspect of it in its totality. The French had good reason to look on their disasters as a judgment. The social and economic developments of the past fifty years had brought about a military as well as an industrial revolution. The Prussians had kept abreast of it and France had not. Therein lay the basic cause of her defeat. (Howard, 1961, p. 1)

So Howard's judgment of the causes of this massive military failure is ultimately technological and systemic. The technological changes to which he refers are familiar: the role that railroads could play in the logistics of nineteenth-century warfare (opportunities that needed to be recognized and incorporated into military plans and the design of operational systems); the advent of new infantry weapons (breech-loading rifles of greater range and speed of loading); and new advances in artillery. The Prussian army incorporated breech-loading rifles (the needle gun) as early as 1843; whereas the French (as well as the British and Austrian armies) retained the muzzle-loader until the 1860s. And the Prussian generals led major advances in artillery in the decades leading up to the Franco-Prussian war, with greater precision and fire power in their Krup guns.

Railroads played a key role in Prussia's mobilization and logistics. The Prussians were able to maintain coordination and organization of their rail system; whereas the French rail system quickly fell into disorder. Howard describes the military potential of railroads in these terms:

> Speed of concentration was only one of the advantages which railways provided. They carried troops rapidly to the theatre of war; and they enabled them to arrive in good physical condition, not wearied and decimated by weeks of marching. Armies needed no longer to consist of hardened regular troops; reservists from civil life could be embodied in the force as well.... Further, the problem of supplying large forces in the field was simplified. (Howard, 1961, p. 3)

And, most significantly, the vast challenge of supplying an army in the field was greatly facilitated by the presence of an effective and well-administered rail system. However, a rail system is not simply a collection of track, locomotives, and rail cars; it is an organized social system with intricate logistics, infrastructure, and planning. Howard takes the view that an important determinant of the outcome of the Franco-Prussian War was the administrative superiority of the Prussians over the French in the management, planning, and deployment of their rail resources. The French rail system was forced into sudden disarray by the attempt to rapidly mobilize a large civilian army. Troops and their equipment were separated, often forever. Mountains of matériel were to accumulate in depots without adequate logistical planning for how to deliver these weapons, ammunition, uniforms, and food to the field. There were sufficient war materials to support an army of adequate size; instead, "it was the chaos of the French mobilisation" that led to the disastrous failure of 1870. On Howard's account, then, the failure of the rail system is a very important cause of the shocking collapse of the French military during the Franco-Prussian war.

The systemic part of Howard's diagnosis is a failure of government: a failure to coordinate ministries and the bureaucracy of the military in pushing forward the reforms that would lead to effective incorporation of new technological possibilities into the order of battle and mobilization. The Prussian army made intelligent use of the General Staff as a learning organization; the French had no comparable organization.

Military failure is perhaps best viewed as a type of organizational failure as well. Elliot Cohen and John Gooch offer a clear analytical basis for trying to understand the military disaster of the Franco-Prussian War (Cohen and Gooch, 1990). Bad generals can cause military disasters; but Cohen and Gooch take the position that "human error" is an explanation we turn to too quickly when it comes to large failures. (Likewise, "pilot error" and "surgeon error" are too superficial in aviation and hospital failures.) Rather, it is important to look for the systemic and organizational causes of failure. They treat war as a complex organizational activity, and they attempt to discover the causes of military failures in a variety of kinds of organizational failure. They identify three basic kinds of failure: "failure to learn, failure to anticipate, and failure to adapt" (Cohen and Gooch, 1990, p. 26). And when these kinds of failure compound in a single period, it is likely enough that the result will be catastrophic failure.

Cohen and Gooch offer a "matrix of failure", partitioning "command level" (from president down to operating units) and "critical task" (communication of warning, appropriate level of alert, coordination) (p. 55); and they demonstrate how mistakes at various levels of command in the several critical tasks can cascade into "critical failures". The cases they analyze include the failure of American antisubmarine warfare, 1942; Israel Defense Forces on the Suez Front and the Golan Heights, 1973; the British at Gallipoli, 1915; the defeat of the American Eighth Army in Korea, 1950; and the French army and airforce, 1940.

It seems that the Cohen-Gooch framework can be usefully applied to the Franco-Prussian War. Each of the key failures occurred: failure to anticipate (especially, failure to anticipate the possible consequences of Prussia's rapid military modernization in the 1850s and 1860s; failure to anticipate the fatal consequences that would follow from the French declaration of war in July 1870); failure to learn (an almost total lack of ability on the part of the French general staff to make sense of the causes of defeat as they occurred in summer and fall 1870); and, most strikingly, a failure to adapt (essentially the same tactics were used at Sedan as had first been applied at Wissembourg; Howard, pp. 204–208).

Emile Zola's treatment of the war, *The Debacle: 1870–1871*, is not a piece of analytical history. Instead, it is a brilliant novelist's best effort to capture the horror and hopelessness of the campaigning in the summer and fall of 1870 from the point of view of the peasant, Jean Macquart. The confusion of endless marches in one direction and then the reverse; the misery of driving rain; the hunger of poorly provisioned campaigning; and the seemingly endless terror of artillery and rifle fire put the reader into the shoes of the foot soldier as he approaches his fate. The novel presents a textured and grim picture of the confusion of the march and the terrors of the battlefield:

> In Remilly there was a dreadful mix-up of men, horses, and vehicles jamming the street which zigzags down the hill to the Meuse. Half way down, in front of the church, some guns had got their wheels locked together and could not be moved in spite of much swearing and banging. At the bottom of the hill, where the Emmane roars down a fall, there was a huge queue of broken-down vans blocking the road, while an ever-growing wave of soldiers was struggling at the Croix de Malte inn (pp. 139–140)

And here, the fateful trap of Sedan, where the larger part of the French army was annihilated:

> The hundred thousand men and five hundred cannon of the French army were there packed together and hounded into this triangle. And when the King of Prussia turned westwards he saw another plain, that of Donchery, empty fields extending to Briancourt, Marancourt and Vrigne-aux-Bois, a waste of grey earth, powdery-looking under the blue sky, and when he turned to the east there was yet again, opposite the huddled French lines, an immense vista, a crowd of villages. . . . In all directions the land belonged to him, he could move at will the two hundred and fifty thousand men and the eight hundred guns of his armies, he could take in with one sweeping look their invading march. (p. 197)

It is an interesting question to ask: to what extent do the skills of the novelist complement the theories of the social scientist and the narratives and analysis of the historian, in helping us to come to a better understanding of the reality of the historical moment? Is Zola's novel a genuine addition to our ability to make sense of this period in France's history? Or is it simply fiction?

6.7 Technology and Culture

Technology is sometimes thought of as a domain with a logic of its own—an inevitable trend towards the development of the most efficient artifacts, given the potential represented by a novel scientific or technical insight. The most important shift that has occurred in the ways in which historians conceptualize the history of technology in the past 30 years is the clear recognition that technology is a social product, all the way down. And, as a corollary, historians of technology have increasingly come to recognize the deep contingency that characterizes the development of specific instances or families of technologies.

As we saw above, Thomas Hughes is one of the most important and prolific historians of technology of his generation. His most recent book, *Human-Built*

World: How to Think about Technology and Culture (Hughes, 2004), looks at technology from a very broad perspective and asks how this dimension of civilization has affected our cultures in the past two centuries. The twentieth-century city, for example, could not have existed without the inventions of electricity, steel buildings, elevators, railroads, and modern waste-treatment technologies. So technology "created" the modern city. (Or rather, technology made the modern city possible.) But it is also clear that life in the twentieth-century city was transformative for the several generations of rural people who migrated to them. And the literature, art, values, and social consciousness of people in the twentieth century have surely been affected by these new technology systems. So technology is a profound historical cause.

This level of analysis stands at the most generic perspective: how does technology influence culture? And how does culture influence technology? What Hughes demonstrates in so much of his work, though, is the fact that the most interesting questions about the "technology-society" interface can be framed at a much more disaggregated level. Recall some of the connections he suggests in his earlier book on the history of electric power (Hughes, 1983):

- Invention (by individuals with a very specific educational and cultural background)
- Concrete development of the artifacts within a laboratory (involving specific social relationships among various experts and workers)
- "Selling" the innovation to municipal authorities (for lighting and traction) and to industrial capitalists (for power)
- Finding investors and sources of finance for large capital investments in electricity
- Building out the infrastructure for delivery of electric power
- Government regulation of industry practices
- Development of an extended research capability addressing technology problems

Each part of this complex story involves processes that are highly contingent and highly intertwined with social, economic, and political relationships. And the ultimate shape of the technology is the result of decisions and pressures exerted throughout the web of relationships through which the technology took shape. But here is an important point: there is no moment in this story where it is possible to put "technology" on one side and "social context" on the other. Instead, the technology and the society develop together.

Hughes also explores some of the ways in which the culture of the machine has influenced architecture, art, and literature. He discusses photography by Charles Sheeler (whose famous series on the Ford Rouge plant defined an industrial aesthetic), artists Carl Grossberg and Marcel Duchamp, and architects such as Peter Behren. The central theme here is the idea that industrial-technological developments caused significant cultural change in Europe and America. Hughes's examples are mostly drawn from "high" culture; but historians of popular culture too have focused on the impact of technologies such as the railroad, the automobile, or the cigarette on American popular culture. See Deborah Clarke's *Driving Women: Fiction and Automobile Culture in Twentieth-Century America* for a discussion of the effect of automotive culture (Clarke, 2007).

Hughes does not consider here the other direction of influence that is possible between culture and technology: how prevailing aesthetic and cultural preferences influence the development of a technology. This has been an important theme in the line of interpretation referred to as the "social construction of technology" (SCOT). Wiebe Bijker makes the case for the social construction of mundane technologies such as bicycles in *Of Bicycles, Bakelites, and Bulbs: Toward a Theory of Sociotechnical Change* (Bijker, 1997; Bijker et al., 1987). And automobile historian Gijs Moms argues in *The Electric Vehicle: Technology and Expectations in the Automobile Age* (Mom, 2004) that the choice between electric and internal combustion vehicles in the early twentieth century turned on aesthetic and lifestyle preferences rather than technical or economic efficiency. This too is a more disaggregated approach to the question. It proceeds on the idea that we can learn a great deal by examining the "micro" processes in culture and society that influence the development of a technology. Technology is not an independent "driver" of history, but is rather itself a historical product densely interwoven with other social and cultural processes.

6.8 Observations from the Examples

The examples presented here are rich in numerous dimensions. Here I will draw out several central observations, as components of a historiography for "meso-history." Most importantly, Sabel and Zeitlin demonstrate that there were multiple feasible modes of economic organization involving different configurations of labor, capital, machinery, tools, product design, and business organization. So the course of western economic development was fundamentally contingent: it could have taken a variety of substantially different branches, consistent with economic, demographic, and political realities. Sabel and Zeitlin demonstrate that the stylized assumption that modernization entails mass manufacture, rigidly specialized machines and tools, and de-skilled labor is incorrect. It is therefore crucial for historians to resist the impulse toward an expectation of unique outcomes. More generally, this case alerts us to the significant degree of choice that exists at every historical moment. Agents choose among multiple feasible strategies, and competing strategies may co-exist for long periods of time. This means that the large-scale outcome is underdetermined by the structural configuration in place at a given time. At the same time, however, Sabel and Zeitlin demonstrate the significant power for constraining and impelling the directions that social change may take that is exerted by existing institutions. Available systems of finance and insurance influence the choices that manufacturers make about maintenance (Reynard, 1999); the political imperative of constraining naval costs impelled the early modern British Admiralty to adopt new architectural approaches to design and construction of ships of war (McGee, 1999); and the advent of the telegraph significantly altered the United States' ability to respond diplomatically to the Franco-Prussian War, in comparison to the equally serious French political crisis of 1848 (Nickles, 1999). The point of flexibility, then, is not that there are no powerful structural influences on the course of history at a given moment; it is rather that these forces are not ultimately determinative of the outcomes. But good explanation will unavoidably need to provide nuanced and theoretically informed analysis of these forces.

Thomas Hughes takes the point about the plasticity of history's course a step further by demonstrating the sensitivity of the course of technology development to the social and political environment. Technological possibilities and constraints do not by themselves determine historical outcomes—even the narrow case of a particular course of the development of a particular cluster of technologies. The technical and scientific setting of a particular invention serves to constrain but not to determine the ultimate course of development that the invention takes. A broad range of technical outcomes are accessible in the medium term. In place of a technological determinism, however, Hughes argues for technological momentum. Once a technology/social system is embodied on the ground, other paths of development are significantly more difficult to reach. Thus there are technological imperatives once a new set of technical possibilities come on the scene; but the development of these possibilities is sensitive to non-technical environmental influences (e.g. the scope of local political jurisdiction, as we saw in the comparison of British, French, and American electric power systems).[4] Further, however, Hughes's work illustrates the very significant gains that come from a micro-level study of the development of important social constructs such as electricity as a power source. By studying the laboratories, universities, banks, city councils, and legislatures through which the electric grid was created in the United States, we are in a very good position to observe both contingent and predictable aspects of the course of development of the technology.

Cronon and Dobbin illustrate a different aspect of the role that technology systems play within historical development: the degree of relative constraint that they create for future historical developments. This is a positive feature of meso-historical explanation: we can explain quite a bit of the changing pattern of economic geography of the upper Midwest by considering in detail the opportunities and constraints that were created by rail connections to the hinterlands and to the major population centers in the East.

Mark Elvin's analysis of China's environmental history illustrates another set of important observations about historical change. One has to do with the dialectic of human activity and natural resources. The availability of resources stimulates various kinds of activity; and these activities in turn influence the future availability of resources. Second, there is an intriguing feature of temporality in Elvin's account: the timeframe of action of farmers, officials, and emperors is different from the

[4] Essays in *Does Technology Drive History*? Shed important new light on the topic of technological determinism (Smith and Marx, 1994).

timescale of the effects that human actions bring about. So the century-long struggle between officials and the Yellow River is one that goes beyond the capacity of any particular official to perceive.

These insights suggest a series of negative maxims as well—historiographic blunders that large-scale history ought to avoid:

- Avoid single-factor explanations (e.g. technological determinism; Wittfogel and hydraulic despotism).
- Be suspicious of grand schemes of paradigmatic historical development (e.g. capitalist development, typical population transition).
- Be cautious in applying uncritically the paradigms and patterns of the European experience to other historical experiences (capitalism, the modernizing state).
- Recognize that historical junctures generally present a range of possible outcomes, depending on the choices of actors; so avoid explanations that impute "historical inevitability" to a particular outcome.[5]

Finally, it would appear that the conceptual framework of "assemblages theory" may be useful in discussing the history of technology and the role of technology in large historical processes (Latour, 2005). (See Manuel DeLanda's *A New Philosophy of Society: Assemblage Theory and Social Complexity* for a review of the theory; De Landa, 2006.) The framework is useful because technology is a social phenomenon that extends from one's own kitchen and household to the cities of Chicago or Berlin, to the global Internet and the international system of manufacturing and design. And similar processes of shaping and conditioning occur at the micro, meso, and macro levels. In other words, perhaps we can understand "technology" at the molar level, as a complex composition of activities and processes at many levels closer to the socially constructed individual. And the novelty provided by the sociology and history of technology is precisely this: to shed light on the mechanisms at work at all levels that have an influence on the aggregate direction and shape of the resulting technology.

[5]For a recent and powerful case for the contingency of a great event of the twentieth century, see Niall Ferguson's analysis of the origins of World War I (Ferguson, 1999b).