Approaches to Technology Transfer in History and the Case of Nineteenth-Century Mexico

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ABSTRACT The transfer of productive technologies from the industrial nations of the North Atlantic to the rest of the world underlay dramatic economic and social transformations in the 19th century. Technology transfer has continued to play a central role in both international economics and national development policy through the late 20th century. Yet efforts to transfer novel technologies across national borders have varied widely, with outcomes ranging from success, to significant adaptation, to failure. This article offers a conceptual model for examining cases of technology transfer, illustrated with examples from Mexico's historical experience of 1870 through 1911. Although this approach comes from an historian's perspective, it is broadly applicable to interdisciplinary interest in technology transfer.

From the 1870s through the first decade of the 20th century, an unprecedented flood of new machines, tools, parts, and novel processes poured into Mexico from abroad. Foreign technologies and know-how provided the physical foundation for the dramatic expansion of transportation networks, extractive industries, commercial agriculture, urban construction, the early appearance of domestic industry, as well as substantial and often wrenching social change. Mexico's experience was far

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from unique. Throughout the 19th century, new technologies flowed from the rapidly industrializing nations of the North Atlantic to continental Europe and more distant corners of the world (Landes, 1969; Mokyr, 1990; Pollard, 1981). This was a world largely divided between a small set of technology exporters and a large number of technology importers. Yet the experience of technology transfer was often not as frictionless, unidirectional, or successful as many contemporary observers anticipated. If those who sought to import and innovate new machines and processes aimed to replicate the experience of economic growth in the North Atlantic, the outcomes of their efforts ranged widely, from local growth and development to long-term economic dependence.

Common views of technology transfer in the 19th century hold that only some societies turned technology transfer into sustained technological advance. A few, like Japan, achieved some degree of domestic control over imported technologies and used foreign techniques to inspire domestic adoption, adaptation, improvement, and subsequent invention (Bernstein, 1997; Jeremy, 1991). Technology transfer in these cases was accompanied, in other words, by expanding domestic creativity and technological capabilities (Rosenberg, 1970, 1982; Ruttan & Hayami, 1973).

Yet experiences like Japan's were exceptional. More commonly, foreign capital, entrepreneurship, and expertise dominated early technology transfer as well as its aftermath. In some settings, foreign technologies enhanced the ability of North Atlantic nations to pursue imperial designs in formal and informal ways. Elsewhere, newly introduced technologies existed in isolated enclaves and were sometimes proved inappropriate in scale and complexity for domestic markets and local expertise. As a result, large disparities existed between imported technology and domestic society and scant diffusion of know-how followed the initial introduction of new machines and processes. Technology transfer in such scenarios did not stimulate domestic skills and creativity, but led instead to ongoing technological dependence (Amsden, 2001; Headrick, 1988; Rosenberg, 1970, 1976). Thus we have two polar scenarios: one in which technology imports helped to promote domestic technological capacity, and the other in which foreign technology yielded technological dependence. In between lay a wide spectrum of historical experiences. All witnessed similar inflows of foreign machines and processes. Yet outcomes varied extensively across countries as well as within countries—across industries, regions, and social communities.

Technology transfer's complex and powerfully transformative nature raises two problems for scholars. The first is methodological: How should we approach a subject that is as historically varied as this one—but for which we have relatively few studies on which to build a common approach? How should we systematically set about the search for explanations to the outcome of particular cases—the factors that shaped a society's propensity to import, adapt, and innovate new technologies and the subsequent story of particular artifacts? Although my perspective is that of an historian interested in 19th century cases, these questions—and the broader issues addressed in this paper—apply to interdisciplinary interests in technology transfer.

The second problem shifts our focus from the transfer of technology to its social contexts and consequences. Why did some societies not only import foreign technologies but also assimilate foreign know-how and develop the capacity to produce locally adapted technologies? How did the importation of foreign techniques and know-how affect the capacity of recipient societies to be technologically creative—to subsequently invent, adapt, improve, and innovate instead of remaining dependent on imported technology and know-how (Ho Koo & Perkins, 1995; Fransman & King, 1984)? For most recipient societies in the 19th century, this issue has been most commonly portrayed as a missing link or a set of obstacles that tended to isolate foreign technologies from domestic society, which consequently limited the development of the willingness, abilities, and institutions that technological creativity depends on.

This paper examines these issues by applying recent insights in the history of technological change to the study of technology transfer. Scholars working on the history of technological change within societies have increasingly argued against technological determinism—that new technologies, once available, will be innovated and that the most economically efficient technologies will dominate and survive. Instead, most technological change is seen as part of an interrelated, complementary, and self-reinforcing process of incremental inventions (or adaptations). New technologies, they point out, emerge from particular historical contexts and are shaped not only by their technological antecedents and economic constraints and incentives, but also by a broader ambience of social relations; cultural values, tastes, and habits; legal standards and requirements; and broader political institutions and organizational structures. Technological change, in this view, is embedded within and contingent upon a contextual dimension including economic, social, and political factors. The new conceptual approaches of *social shaping* and of *technological systems*—heavily influenced by earlier work in the sociology of science and technology—view technology not as exogenous to society but as an interrelated part of society and social forces (Bijker, Hughes, & Pinch, 1987; Mackenzie & Wajcman, 1999).

New approaches to technological change have largely evolved through studies of change *within* societies and have not been systematically applied to the transfer of technologies *between* societies (Cowen, 1987; Hughes, 1987; McGaw, 1987; Nye, 1990). Yet these approaches are especially relevant to technology transfer because our primary interest involves cases in which the contextual environment of the countries of origin and reception often differ markedly. We can readily observe, for instance, that widespread international flows of technology in the 19th century produced results that varied widely across time, regions, and sectors, and seldom followed an orderly and rational path. Rarely were transferred technologies impervious to new contexts, and identical technologies introduced into different societies yielded different outcomes. The challenge is to systematically explore the sources of these different experiences and their consequences for local social and economic development. My goal is to provide a useful framework for comparative studies of technology transfer in history—a heuristic approach that can help us first work toward recreating the varied experiences of technology transfer, and second, help us to explain that process and its impact on domestic technological capabilities. The following sections of this paper lay out two essential features of any particular story of technology transfer: its temporal and contextual dimensions. This conceptual approach is informed by recent work on the social context for technological change as well as by a broad familiarity with the experience of one recipient country.

Mexico provides a useful case study to illustrate an approach to 19th century technology transfer. Although technology transfer after 1950 has received a great deal of attention, work on 19th century cases remains scattered. Classic success stories and colonial settings receive most attention. Mexico's experience fell between the contrasting experiences of the United States and Japan on one hand, and cases like India, Egypt, or Indochina on the other. Mexico's experience is arguably typical of a broader range of experiences, including those of other Latin American and postcolonial states. Although the secondary literature provides anecdotal glimpses of technology transfer during the crucial socioeconomic transitions of 19th century Latin America, virtually no work systematically addresses the topic (Bulmer-Thomas, 1994; Coatsworth & Taylor, 1998; Haber, 1997).

Mexico between the 1870s and 1910 provides an ideal setting to do this. Before the 1870s, Mexico was in many ways a nation of isolated and localized markets where most business activity was based on personal relations, a result of 50 years of post-independence political instability and economic stagnation. Productive technologies differed little from those used in the late 18th century. Yet by 1910, rapid economic change meant that business was generally conducted within national and international markets (Haber, 1989; Kuntz Ficker, 1995). In Mexico's late 19th century transition, new productive technologies increasingly altered both production and lives by substituting mechanical methods for what had previously been homemade, handmade, and locally made. Mechanization began to appear after 1870 in extractive activities, transportation, power and light, construction, manufacturing, food processing, and, to a lesser degree, agriculture. Steam engines, electric generators, sewing machines, cyanide processing, cigarette rollers, glass-bottle blowers, tortilla machines, and cement (among many others) began to alter not only the nature and scale of production but also the lives of many thousands of Mexicans who found work in new industries, who consumed the products of new factories, or whose lives were affected in many, less direct, and often involuntary and painful ways. Imported machines and processes underlay all new activities (Barragán & Cerutti, n.d.; Sánchez Flores, 1980).

In one view, this experience of technology transfer and economic transition simply happened to Mexico. Driven by rapid expansion of international trade and investment, the dominant agents were foreign investors and foreign interests from the North Atlantic who aggressively sought markets and investment opportunities around the globe. In this they were aided by a small circle of domestic elites in the Mexico of Porfirio Díaz, who governed the country as modernizing dictator from 1876 to 1911. Although those close to the center of political power profited as intermediaries, and despite some moderate growth of an industrious, urban middle class, most Mexicans were left outside the benefits of modernization and growth. One outcome, in this view, was the dominant position of foreign capital, foreign technique, and foreign know-how. Technology imports served to weaken domestic capabilities, leading to long-term dependence and underdevelopment. The other principle outcome was social discontent and the onset of 10 years of revolutionary violence and civil war in 1911.

Although conditions of political dictatorship, extreme social and economic inequality, and the dominant place of foreign interests remain the cornerstones of any understanding of Porfirian Mexico, recent scholarship has revised and questioned some aspects of this conventional view. Domestic manufacturing industry occupied a relatively large and dynamic place in economic growth, public policy appears more coherent and even-handed than previously asserted, and entrepreneurial Mexicans played a significant role in the process (Beatty, 2001; Haber, 1989; Marichal & Cerutti, 1997). Moreover, there are indications that Mexico's experience of technology transfer was substantially more complex. The Mexican experience varied across regions and economic sectors and ranged from successful cases of transfer and the subsequent development of Mexican innovation, to transfer and ongoing technological dependence, to the lack (or failure) of transfer altogether. With such intra-national diversity, the Mexican case fills an important gap in the literature on 19th century technology transfer. It also provides useful illustrations to the conceptual approach outlined below, one that is broadly applicable to comparative international settings. In this paper, brief glimpses of the Mexican experience illustrate the temporal and contextual dimensions of this conceptual approach to technology transfer. These cases are drawn from the author's previous work (2001), from ongoing research on a new project, as well as from extant secondary anecdotes—used here to suggest an agenda for further research.

THE TEMPORAL DIMENSION OF TECHNOLOGY TRANSFER

Scholars have long traced case studies of technological change through successive stages of development, including research, invention, innovation, and diffusion. Interactions and feedback between stages have been added to simple linear models, including ways in which post-invention experiences yield modifications to earlier ones through learning by doing, learning by using, learning by selling, and the like (Arrow, 1962; Rosenberg, 1982; Thomson, 1989). Some scholars have gone further and questioned the viability of any kind of stage model for understanding technological change, arguing that forward-looking linearity tends to privilege an overly progressivist, teleological story that deemphasizes failure and ignores ways in which technological change is fundamentally shaped by complex contextual factors (Callon, 1987; Pinch & Bijker, 1987). Nevertheless, it would be a mistake (as well as historically inaccurate) to jettison the temporal context altogether. Chronology matters because the challenges to technologies' viability vary over time.

Figure 1 presents the temporal dimension of technology transfer. The figure identifies four phases in the possible story of any transferred technology. Each phase incorporates a complex array of possible activities and actors, and each phase is identified here by the one activity that predominates: decision, acquisition, innovation, and diffusion. This conception is linear because no phase can occur without the previous ones. However, this formulation does not imply a unidirectional, forward-looking, deterministic stage model. Boundaries are fuzzy and overlapping; substantial

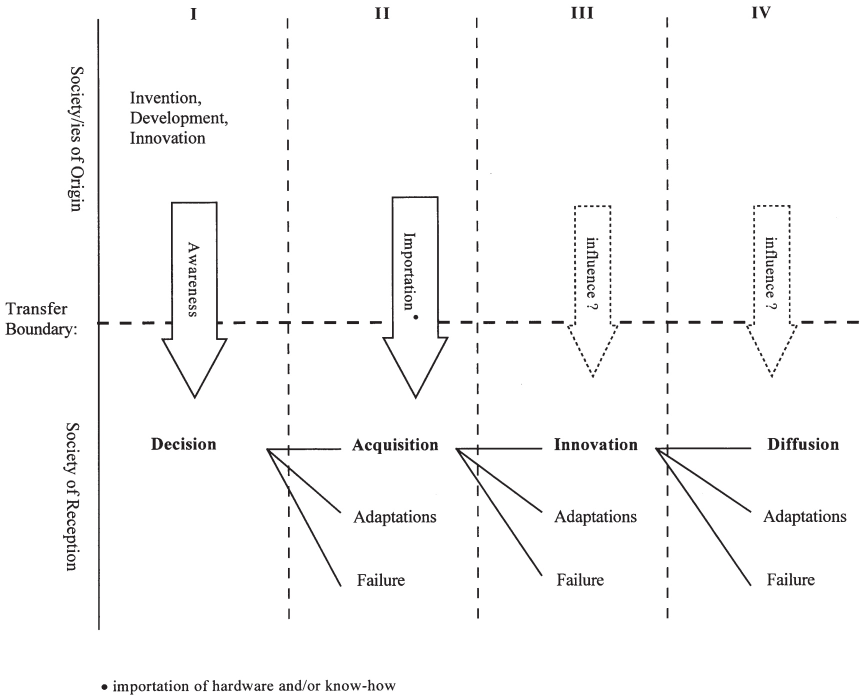

Figure 1 *The temporal dimension of technology transfer.*

opportunities for interaction exist; and multiple paths are possible at any point, including successful transfer, adaptation, or failure. Each outcome provides useful information; indeed, failures often yield richer explanations than do successes. Within each phase, activities are set within an ambience of contextual factors that we examine more closely in the next section of the paper.

decision

Decisions to pursue the introduction of any particular technology begin with actors attuned to local opportunities and foreign techniques—the primary "consumers" of imported technology (Cowen, 1987). Based on the Mexican experience, we can divide these consumers into two groups whose interests relative to the introduction, innovation, and diffusion of foreign technologies differed substantially. For large-scale production technology (including automated machines to roll cigarettes, blow glass bottles, weave textiles, and even larger-scale production units for mineral refining, steel production, or cement manufacture), they generally included a small number of well-financed individuals or firms interested in acquiring and innovating a particular technique. These might include government agencies, public works contractors, utilities companies, and firms as well as individuals. In contrast, the primary consumers of small-scale, multiuse, product technology (such as steam engines, boilers, sewing machines, and tools) generally comprised a much larger and more diverse number of individuals or firms. Most primary consumers in countries like Mexico were not multinational actors (as they would be after World War II), nor were they colonial agents. Foreign technologies were rarely imposed, and with the exception of large-scale public works and utilities, independent agents of diverse nationalities on both sides of the border jointly made decisions to pursue technology transfer. Indeed, the vast majority of entrepreneurial projects using foreign technologies involved some kind of partnership between Mexican and foreign actors (Beatty, 2001; Wilkins, 1998). All perceived an opportunity (as importers) for the introduction of a foreign technique or (as exporters) opportunities to open new sales markets.

Because any technology transfer requires investment, and because we are primarily concerned here with productive technologies, we can expect that most decisions to pursue the introduction of a foreign technology would heavily weigh economic factors: reducing costs, increasing revenues, or putting new products on the market. This does not necessarily imply that economic motives were paramount and necessarily determinant, as we shall see below when we turn to the contextual dimension. It does imply, however, that in many cases these actors faced a choice of techniques. For potential technology importers, there were often several available alternatives based on factor requirements, measuring systems, engineering styles, or age. Choice frequently meant picking from a shopping list of alternatives (Bruland, 1989; Saxonhouse, 1970).

In Mexico, decisions to pursue large-scale production technologies illustrate this phase of the process. Throughout the 19th century world, glass bottles housed everything from patent medicines, to hair tonic, to liquor, and much else. But in 1900 the fastest growing source of demand for glass bottles in Mexico was the beer industry. As late as 1890 bottled beer was virtually unknown. It was, in the words of one observer, an "aristocratic beverage" drunk by foreign expatriates and few Mexicans, mostly in the northern states (Barragán & Cerutti, n.d.; Haber, 1989; Hibino, 1992). Existing breweries were small-scale, highly specialized affairs catering to the tastes and pocketbooks of a narrow social group; most of Mexico's limited beer for consumption came from the United States. Yet a mere decade and a half later, Mexico's alcohol culture had been transformed, at least in urban areas. By 1907, national consumption of bottled beer (replacing the traditional *pulque*) had risen to over 50 million liters annually and was marketed aggressively and competitively in all major cities. Changing tastes reflected changing attitudes, and as the editors of one newspaper suggested, it was beer, not *pulque*, that brought men "comfort and happiness, and open[ed] the way to a higher civilization" (Bunker, 1997, p. 234).

But as new, large-scale breweries opened and expanded in Monterrey, Chihuahua, Toluca, Puebla, and Oaxaca, all faced a common constraint: the bottles to put the stuff in had to be blown by hand, and each brewery had to hire its own small and expensive force of largely émigré glass blowers, who invariably could not keep up with demand. This bottle supply problem was solved first in the United States with the development of the Owens automatic glass bottle–blowing machine and its commercial use in early 1905 by the Toledo Glass Company. As with most new developments in the North Atlantic economies, it did not take Mexico's large brewers long to learn of and try to acquire this new technology. In June 1905 agents from Mexico's two largest breweries in Chihuahua and Monterrey made hasty and competing trips to Toledo in an effort to sign an exclusive contract. By September it was Juan Brittingham of the Cervecería Chihuahua who had won this race and paid U.S. $100,000 for two machines and their Mexican patent rights. Similar decisions to pursue newly developed automated production machinery played out in the textile industry, the cigarette industry, and the steel and cement industries, among others.

In contrast, the initial decisions to pursue the introduction of more generic, small-scale products like steam engines, electric motors, sewing machines, and diverse parts and tools were often (although not always) made by firms and sales agencies abroad. The Singer Company was the best known and most aggressive, sending a veritable army of sales agents across the border and around the world (Davies, 1976). Its agents—typically young men, dressed neatly and conservatively—traveled on a budget from town to town, often on foot. From Mexico's largest cities to small *mestizo* towns like San José de Gracia in the Western state of Michoacan, they showed up at least as often as the priest, for whom children sometimes mistook them. Between 1900 and 1910, Mexico imported sewing machines valued at over U.S. $10 million, roughly 400,000 individual units. Singer was not alone in this endeavor, and was joined by a host of manufacturing and exporting firms in the United States and Europe, including the Platt Brothers and the Babcock & Wilcox firms, Westinghouse and Loomis Pettibone, and the Siemens, Oerliken, and Otto companies from Germany, among many others. In all these cases, initial decisions to pursue technology transfer were based on perceptions of economic opportunity and a belief that foreign technologies—already developed and innovated abroad—could find profitable use in Mexico.

acquisition

Once made, decisions to pursue the introduction of foreign technology might yield several possible outcomes. Figure 1 aggregates these in three categories: the successful *acquisition* of a foreign technology, an acquisition that involves substantial *adaptation* to the foreign design, or a *failed* effort to pursue its introduction. Acquisition includes either the importation of the physical artifact itself or the means of replicating it in the recipient society, usually by importing knowledge embodied in blueprints, plans, or skilled persons. In most cases it meant a combination of the two. In the acquisition phase, the primary actors are the same as those in the first phase, but now those who made the initial decisions are likely joined by several kinds of additional actors. These could include foreign suppliers or proprietors, as well as potential investors in the acquisition, importation, and future innovation of the foreign technique.

Marketing strategies adopted by actors on either side of the border are crucial at this phase. Strategies adopted by foreign suppliers could limit the options available to consumers in countries like Mexico (Beatty, 2001, ch. 5). In the case of large-scale production technologies, foreign suppliers usually sought to maximize returns on the small number of units they were likely to sell. Their strategies often included the transfer of patent rights to buyers in return for monopoly pricing or a stream of royalties. In contrast, foreign suppliers of relatively small-scale product technologies usually sought to market widely and build market share through the use of trademarks, advertising, or sales agencies. In both cases, the acquisition of foreign techniques likely involved substantial negotiation over the terms of formal or informal contracts for hardware and know-how. In all cases, the strategies adopted by foreign suppliers and the technology's consumers in Mexico in the acquisition phase shaped its development in the new, recipient context.

Acquisition typically involved some kind of formal contracting with suppliers abroad. For large-scale production technology we have glimpsed this in the glass bottle case. There, the Toledo Glass Company received patent rights to its novel machine from the Mexican government and then sold the physical artifact, the services of technical consultants, and the Mexican patent rights as a package to Juan Brittingham and his financial backers. Although the Ohio company usually licensed its machinery in the U.S. market and collected royalties based on output, its concern with the unknown size of the Mexican market led to a negotiated one-time monopoly price. A similar story played out in the cigarette industry. There, the Bonsack Machine Company of North Carolina took its first Mexican patent in 1891 for a newly developed machine to automatically roll cigarettes. It then sold both the rights and machinery to Antonio Basagoiti of the Tabacalera Mexicana, one of Mexico's three largest cigarette manufacturers (Haber, 1989; Sánchez Flores, 1980). In contrast to the glass bottle case, here there were competing foreign technologies. The French Decoufle company sold its rival machines and patent rights to Tabacalera's biggest competitor, the Buen Tono firm of Mexico City. In these and other cases, the acquisition of large-scale production technology involved negotiated contracts between Mexican entrepreneurs and foreign proprietors and manufacturers. In all cases, imported hardware was accompanied by imported technicians to assist with installation, operation, and at least initial maintenance. In no case of this sort was a Mexican firm able to replicate foreign know-how independently.

Small-scale product technologies typically came to Mexico as a result of a different type of sales contract. These technologies found much broader markets in Mexico (and elsewhere); therefore, multiple foreign suppliers sought to maximize revenue by selling widely and competing among themselves for shares of foreign sales markets. Patent rights, trademarks, advertising and pricing strategies, and networks of sales agents and distribution agencies all served this purpose. Singer, Babcock & Wilcox, and others pursued most of these in Mexico.

There was one other option for those interested in importing foreign techniques: acquiring the know-how sufficient to replicate it without purchasing the artifact or the proprietary knowledge. This was the default option for technologies like chemical processes and novel products derived from new combinations of readily available materials. But for the majority of imported technologies—machines and tools and their parts—the critical question was whether a recipient society like Mexico had the capacity to pirate, reverse engineer, or otherwise replicate foreign technologies. For most kinds of 19th century productive technologies, the most important prerequisites for imitation were sufficient human capital, an iron industry capable of producing low-cost, high-quality material, and machine tool capabilities (Rosenberg, 1976; Temin, 1964). Whether recipient societies in the 19th century possessed these requisites and could consequently replicate some kinds of foreign machines and tools is the key issue. In Japan, the answer was apparently affirmative. Mexico, in contrast, lacked this foundation. Indeed, one of the striking characteristics of its late-century industrialization was the construction of Latin America's largest and most modern steel foundry in a country that lacked a modern iron industry (Gómez Galvarriato, 1990; Haber, 1989; Riguzzi, 1996).

Yet it was not entirely inconceivable that Mexican firms might undertake the independent replication of small-scale product technologies. The best known example involved the domestic invention, development, and manufacture of machinery to replace hand methods in the processing of the native *henequen* (sisal) plant, primarily in the Yucatán (Soberanis, 1989, pt. II). More surprising and still unresearched is the apparent success of other mechanical enterprises to produce grain mills, automatic tortilla machines, and even steam engines and boilers (Beatty, 2001, p. 73; Pilcher, 1998).

innovation

Once initial consumers acquired foreign technology, they faced the challenge of its innovation, or first commercial use. In most settings (from factory, to mine, to household), this entailed a series of activities centered around installing, operating, and maintaining the novel machines or processes. Although we can identify a common sequence of events, there was rarely a unidirectional path. On one hand, imported techniques carried with them a certain inertia, embodied in the sunk costs of design and manufacture and reinforced by the conceptual models held in the minds of those foreign or national actors involved in innovation in the recipient country. On the other hand, histories of imported technologies tell us that outcomes varied widely. Efforts to install and operate often involved minor or substantial modifications to the design of imported technologies. Sometimes these were reactive in nature, forced by new circumstances in the recipient society. Sometimes adaptations were proactive, taking advantage of new opportunities, especially in the product market. Failures to innovate were common and often outnumbered successful innovations. Adaptation or failure derived from efforts to install new technologies as well as from problems encountered in maintaining, repairing, and troubleshooting. All of these scenarios played out in Mexico (Beatty, 2001).

Innovation introduced new sets of important actors and social groups who interacted with imported technique and know-how in various ways. These could include new investors, legal agents, engineers, technicians, workers, regulatory officials, and of course the consumers of end products. The innovation of imported large-scale production technologies in Mexico frequently required the services of imported technicians or engineers. This was the case across a wide range of economic activities: railroad construction, oil drilling, mineral extraction and refining, the construction of large-scale public works, and many manufacturing settings. As we have seen in the glass bottle and cigarette examples, contracts for hardware often included the services of foreign technicians—Toledo Glass sent two to help install and operate the bottle-blowing machinery. In cases like railroads and public works, usually undertaken directly by foreign concessionary firms, imported human capital was also part of the larger contractual package (Kuntz Ficker, 1995; Kuntz Ficker & Connolly, 1999; Kuntz Ficker & Riguzzi, 1996). For small-scale, more generic product technologies that were retailed widely, primary consumers bore less of a technical burden. A combination of simpler technical requisites and broader diffusion meant that the use and operation of technologies like steam engines, boilers, sewing machines, and diverse tools required little external expertise.

Even with foreign expertise, efforts to innovate imported technologies in Mexico frequently encountered obstacles. Although anecdotal accounts in the extant secondary literature tend to present stories of successful innovation, this is a biased view. Failure was a common experience. Of the over 300 firms that applied for federal tax and tariff exemptions through the Mexican government's "New Industries" program between 1893 and 1910, to take one sample, only eight eventually entered commercial production (Beatty, 2001, ch. 6). Most complained of a range of obstacles—contextual factors that prevented the hoped-for frictionless adoption of foreign technologies. In some cases the critical problem lay in the natural environment—the seasonal aridity of much of central and northern Mexico or the scarcity of local sources of wood, ore, or coal. Both La Industrial, a Yucatecan fiber products firm, and the Compañía Nacional de Hierro y Acero (National Iron and Steel Works) in central Mexico cited the scarcity of local fuel and the high cost of imported coal as reasons for suspending work in their new factories. In other cases the critical problem lay in societal issues. Several new firms found their access to local supplies of water and wood blocked by the existing property rights of neighboring communities and found negotiating around these obstacles extremely difficult. Similarly, locating domestic suppliers of intermediate inputs often proved debilitating (especially industrial chemicals and semi-processed metals). In the absence of local supplies, many turned to foreign markets only to find that Mexico's tariff structure sometimes made imports of intermediate products unprofitable. Finally, innovation frequently required external financing. Here, the poorly developed nature of Mexican capital markets presented yet another obstacle to successful innovation (Maurer & Haber, 2002). Any systematic exploration of technology transfer in 19th century Mexico must explain failures alongside successes; indeed, it is often these kinds of obstacles that best highlight the most decisive elements in the relationship between imported technologies and the recipient context.

diffusion

Whether diffusion among a larger number of users followed the commercial innovation of foreign techniques depended on multiple factors. First, it depended on the capacity of additional actors to replicate the experience of innovation. If the first commercial use required proprietary machinery that could not be readily replicated in the recipient country, if it involved monopoly rights to such machinery or processes, or if it involved tacit knowledge that additional users could not easily obtain, then diffusion was unlikely. Second, the diffusion of foreign techniques also depended on the scale of the particular technology relative to sales markets (Beatty, 2001, ch. 5). Large-scale technologies with productive capacities close to domestic demand would not likely diffuse beyond one or two users. Small-scale product technologies (steam engines, tools, or sewing machines) could potentially diffuse much more widely. In between lay a broad spectrum of possibilities. In any case, diffusion is rarely inevitable or uniform within societies. Cases of monopolization or enclave production proliferate in historical experiences. When it occurred, the rate and direction of diffusion often diverged within countries and societies, with adoption patterns varying by region and conditioned by geography, social factors, and economic conditions (Todd, 1995).

In Mexico, the experience of successfully innovated foreign technologies ranged widely. For most large-scale production technologies, commercial use remained concentrated among a small number of firms. In the cases of the Owens automatic glass bottle–blowing machine and automated cigarette rolling machines, this was a function of legal, patent-based monopolies. In glass, Mexican assignee Juan Brittingham initially considered sublicensing the machinery to multiple Mexican firms, but he eventually established a partnership with the Cervecería Cuauhtémoc brewery in Monterrey and together they established the glass firm Vidriera Monterrey. With exclusive use of the Owens machinery (and with no competing automated designs available in the international market), they went on to dominate both the beer and glass industries in Mexico (Barragán & Cerutti, n.d.; Haber, 1989; Hibino, 1992). A similar story played out in the cigarette industry. Although two Mexican firms acquired competing foreign cigarette rolling machines (the Bonsack and Decouffle designs), one of these—Buen Tono—won a patent infringement case against the other in 1900. By 1907, the successful litigant dominated Mexican cigarette production and owned controlling shares in the other two major tobacco firms (Haber, 1989; Sánchez Flores, 1980). Even in the absence of political factors like patent rights, however, the limited size of the Mexican market made diffusion beyond a small number of adopting firms highly unlikely for most large-scale production technologies.

Small-scale product technologies faced an entirely different environment for diffusion. Here the interests of foreign suppliers favored widespread diffusion among many potential Mexican consumers and relatively few obstacles arose to hinder diffusion. More interesting perhaps is the fate of another type of imported technique: chemical processes. The most important of these in late-nineteenth-century Mexico was the MacArthur-Forrest cyanide process for separating gold and silver from their host ores. First developed in Great Britain, by the early 1890s its British proprietary company had taken patents in Mexico and other gold-producing countries throughout the world (Todd, 1995). In 1900, the British company transferred its Mexican rights to the subsidiary Mexican Gold & Silver Recovery Company, established expressly to manage the licensing of use rights under the Mexican patent. Because the process resulted in far greater yields of gold and silver per ton of ore than traditional amalgamation methods, the process diffused rapidly throughout Mexico's northern mining districts, usually replicated without an official license. In such cases the Gold & Silver Recovery Company demanded royalties on the threat of an infringement suit, and its 1906 Supreme Court victory against one pirate enabled it to successfully collect moderate royalty payments from most of those who had adopted the process (Bernstein, 1965; Sánchez Flores, 1980; Velasco Avila et al., 1988). Cyanide diffusion proceeded rapidly because the inducements to adopt were high, whereas the barriers to doing so were low: productivity exceeded previous techniques; skilled and experienced engineers could be readily imported from the United States or hired away from competing mining camps; and the chemical solution itself could be cheaply transported across the border.

domestic technological capacity

How should we think about the relationship between the temporal dimension of technology transfer and our concern with domestic technological capabilities? Technological learning underlies the relationship between imported knowledge and domestic capabilities (Amsden, 2001; Fransman & King, 1984; Mokyr, 1990; Villavicencio & Arvanitis, 1994). *Learning* implies the development or acquisition of the capacity to assimilate technological knowledge and deepen technological creativity. Learning is manifest not only in the ability to import and innovate foreign techniques, but more importantly in the subsequent ability to invent, replicate, adapt, repair, innovate, improve, and operate *independent* of imported machines and know-how. In some 19th century contexts, a wide gulf separated foreign technologies and domestic capabilities. In other cases, obstacles were minimal or malleable, and transfer stimulated domestic creativity. Mexican efforts yielded mixed outcomes, and successful transfers ranged from isolated enclave activities to some that were closely linked to and assimilated by domestic society.

Technological learning can occur in any of the four phases of technology transfer as a result of two types of activities: the acquisition and assimilation of technical knowledge from abroad, and intimate interactions with imported technologies in the recipient context (see Figure 1). In the decision phase, learning occurs through the acquisition of information about the range of foreign technological possibilities. The potential for learning is increased with the number of venues for exchanging technological information across borders: human travel and migration in both directions, commercial trade, and the availability of foreign publications, including trade journals, patent specifications, and manuals. In the acquisition phase, learning continues to be primarily a function of access to foreign knowledge, now narrowed to knowledge about a particular technique. How much learning takes place depends in large part on how users in the recipient country acquired technological knowledge through negotiation with foreign suppliers. Because the physical artifact and accompanying information represent only part of the knowledge necessary to operate, adapt, improve, or replicate the technology, simple acquisition may not imply much technological learning. As we have seen in the Mexican cases, the primary interest of foreign suppliers was to sell or license hardware, and they consequently had little interest in transferring the tacit or implicit aspects of the particular technology. On the other hand, we will see below that in both the glass bottle and cigarette cases, Mexican consumers developed the capacity to not only operate but to subsequently improve foreign techniques, developing their own technological capabilities.

Learning at the innovation phase comprises both continued acquisition of foreign expertise and the first-time direct interaction between foreign technology and different actors and groups in the recipient context. In our 19th century cases, the former took the form of foreign advisors and technicians who oversaw and troubleshot the installation process, especially in cases of complex production machinery. Levels of interaction varied widely, depending on the degree to which innovation came at the hands of temporary foreign technicians or with domestic managers, technicians, and workers. Finally, if learning is a function of the number of users and the nature of their relationship with the technology, then the greatest potential for learning occurs when and if foreign technologies diffuse widely through society. The potential for learning at each phase of the process varies considerably, however. Acquisition of knowledge does not necessarily imply its assimilation, mastery, or the development of domestic technological capabilities. At every phase of the process, the limits and potential of technological learning are conditioned by the contextual environment of imported technology—by social, cultural, and political as well as economic factors. Although the temporal dimension of technology transfer aims to reconstruct its narrative story and identify points of conflict, adaptation, or failure, it alone cannot explain a particular historical experience. We will return to the relationship between imported technology and domestic capabilities after considering the contextual dimension for technology transfer.

THE CONTEXTUAL DIMENSION

Each phase in the chronological life of any transferred technology—from initial interest to some degree of stabilization following innovation, diffusion, adaptation, or failure—is set within a complex contextual environment. Scholars working on the social shaping of technology argue that considerations of technical superiority and economic efficiency cannot alone explain the course of technological change (Bijker et al., 1987; Mackenzie & Wajcman, 1999). As with technological change, experience of technology transfer requires a consideration of an interrelated network of technical, economic, social, environmental, and political factors that mediate the relationship between imported knowledge and recipient society. Complementary to "social shaping" is the "technological systems" approach (Callon, 1987; Hughes, 1987; Law, 1987). Technologies are seen as embedded in a seamless web of relations with interrelated and heterogeneous contextual factors. Although work on technological systems arose primarily from studies of large-scale, relatively centralized systems like electric light and power, its essential concepts are applicable to a much wider range of technologies. Placing technologies within networks of relations serves to highlight conflicts between the technology and its environment. It illustrates how conflicts in one part of the system might induce innovations or adaptations in other parts of the system: reverse salients, bottlenecks, or focusing devices (Hughes, 1987; Rosenberg, 1976). Such conflicts, or friction between foreign technologies and some component of the recipient context, often lay at the center of adaptation or failure in stories of technology transfer. Together, these approaches facilitate a systematic exploration of how technology transfer is embedded in the particular contextual details of a historical time and place.

The contingency of time and place quickly become evident in comparative studies, both between and within countries. The cyanide mineral separation process provides one example. Cyanide's story in nearly half a dozen mining countries was largely a political one involving the novelty of the patented process. Yet political maneuvering and court battles played out differently within varying institutional settings. Even within nations, regional differences in political interests and in environmental and social factors yielded diverging experiences (Todd, 1995). The international adoption of new textile machinery provides another case. Here we can observe substantial national differences in the ratio of workers to looms and spindles—partly the result of differential levels of skill and experience, partly the result of customs and preferences, and partly the result of the particular balance of power between labor and management in each setting (Gómez Galvarriato, 2000). Historians of technology transfer have not wholly ignored the contextual dimension, but neither have they treated it systematically (Headrick, 1988; Inskter, 1990; Jeremy, 1981; Mokyr, 1990). Figure 2 presents the contextual dimension for technology transfer, adapted and informed by recent work on the social construction of technology (Bijker et al., 1987).

transferred technology

Transferred technology lies at the center of this conceptualization only because it is the primary subject of our study. It is itself just one element in the network, as are many other kinds of actors, artifacts, and contextual factors. We could just as easily de-center technology and shift our primary focus to the primary consumer, a relevant social group, or any other component of the interrelated network (Cowen, 1987). Our primary concern is with the solid lines in Figure 1: the relations between the particular technology and its relevant contextual factors—those system components for which there is evidentiary influence or plausible reason to suspect influence. These lines do not indicate unidirectional causality—the influence of context on artifact—but rather the potential for mutual and interdependent influence (Mackenzie & Wajcman, 1999). In most cases, there exist layers of systems and subsystems as well as indirect or secondary relations between components. Some elements of the system will be more malleable, whereas others are more obdurate and intractable.

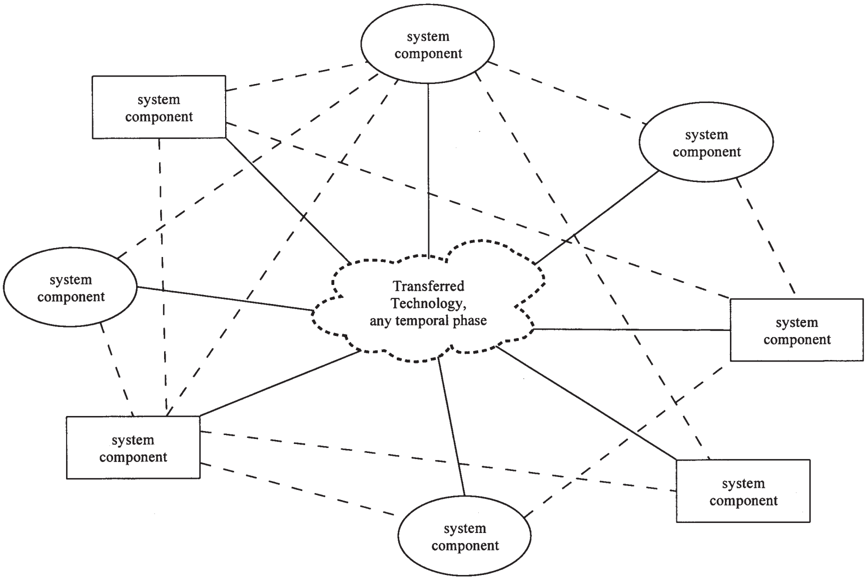

Figure 2 *The contextual dimension for technology transfer.*

Take the case of cement in Mexico. Between 1890 and 1910, Portland cement provided the foundation for the biggest construction spree in Mexico since the rebuilding of the razed Aztec capital of Tenochtitlán by Cortés in the 16th century. Over four centuries later, builders used prodigious quantities of cement in the concrete structures of new port facilities, railroad bridges and abutments, and especially for urban construction projects that remade the face of Mexico City (Barragán & Cerruti, n.d.). Anecdotal glimpses of this story present several puzzles, however. One concerns the persistent reliance on imported cement and its relatively late replacement by domestic production. What factors stood in the way of innovating cement production in Mexico? After all, as a relatively high-bulk, low-cost good, importing cement from suppliers in the North Atlantic raised material costs by nearly 300% in the 1890s (Beatty, 2001, Table 9)! Moreover, replicating foreign techniques of cement production in Mexico apparently did not require the acquisition of proprietary rights, one-of-a-kind machinery, or even significant tacit knowledge concerning production techniques. By 1907, several new plants had begun operation and cut substantially into imports but, in contrast to other foreign technologies, the delay between development abroad and innovation in Mexico had been relatively long. A second puzzle concerns debates over the use of cement in urban construction. On one hand, critics disparaged the "architectural pretensions" of poured concrete molds and argued for the aesthetic and cultural superiority of traditional hand-carved stonework. To this they added a defense of the livelihood of the largely indigenous stonecutters. On the other hand, proponents offered the powerful logic of relative costs and also pointed out the greater earthquake resilience of concrete. This argument gained strength following the April 1907 tremors that left concrete block buildings untouched next door to heavily damaged stone buildings. A comprehensive story of the introduction of cement technology (both the material and, later, its production) to Mexico has not yet been told. It is likely, however, that tracing the network of relations among the multiple social, technical, and economic components of cement's network will help to explain a story that involved a campaign by cement's primary consumers that built arguments on grounds of economic cost and efficiency, but that also had to contend with cultural tastes and social interests.

System Components. System components include any contextual element with direct or indirect influence on the development of the technology in question through the temporal phases of decision-acquisition-innovation-diffusion (Law, 1987). They include human actors and social groups, ranging from the primary consumer of the particular technology to exporters, importers, investors, scientists, engineers and technicians, government officials, firms, social critics, workers, and final consumers. System components include economic linkages, such as supplies of raw materials, processed intermediate inputs, and capital goods. System components also include societal institutions, both formal and informal. Among these might be found regulatory policies and political institutions and diverse cultural practices, tastes, preferences, and ideologies. They include various kinds of economic markets (themselves shaped by political institutions, social relations, and cultural practices) and social organizations like firms, banks, business associations, and labor unions. Societal institutions might also include sources of scientific and technical knowledge such as the educational system, training programs, and venues for imported publications. Finally, they include the physical environment itself: sources of raw materials as well as land, water, and climate.

Few if any of these contextual components are static or fixed. Nor is there a relevant environment outside the technological network; all relevant aspects of the contextual environment need to be identified and located within the network (Callon, 1987). Take, for instance, two factors sometimes portrayed as fixed characteristics of the recipient environment: natural resources and cultural values. As historical cases of technological change and transfer suggest, neither can be seen as wholly external to the technological system, and both are to some degree amenable to the influence of imported technologies (Wright, 2001). The challenge is to identify the points of conflict and tension between imported technique and the recipient environment, and then trace the ways in which conflict shapes each side. Finally, few components are entirely homogenous. We can easily imagine "government," for instance, as a many-headed party, exhibiting different views between branches, between national and local policies, or between individual bureaucrats within the regulatory framework. Likewise, consumers likely diverge along lines of gender, age, class, or region, among other possibilities. Finally, individuals with particular ideas, visions, and talents often play decisive roles within technological systems. Such individuals might be heroic systems builders, but more often comprise a range of entrepreneurial figures who play less decisive yet still key roles in decentralized and less hierarchical networks. Although the technology itself lies at the center of our approach, much of our attention will fall on the technology's primary consumer. These primary agents sought to implement foreign techniques and confront obstacles, and subsequently directed their attention to the most tractable elements of the network (Cowen, 1987).

The web of relations mapped in Figure 2 represents the contextual dimension of technology transfer at any temporal phase. Mapping the relevant components enables us to systematically consider the points of contact, and especially those areas of conflict between imported technology, on one hand, and particular elements of the local environment, on the other. Once identified, these areas of conflict point toward experiences of failure, adaptation, or surmountable discrepancies—the interesting questions in studies of technology transfer. They force us to examine the ways in which both foreign technologies and local environments are malleable and lead us eventually toward the relationship between foreign technique and domestic capabilities.

In the Mexican experience, research has not yet traced out complete contextual dimensions for cases of technology transfer. Nevertheless, anecdotal evidence suggests its explanatory importance. At first, fairly straightforward stories of technological determinism seem plausible. In the glass and cigarette cases, for example, automated technologies were developed abroad to replace hand methods, entrepreneurs in Mexico became aware of these technologies as they faced expanding domestic markets, and the most aggressive obtained the new technology and innovated it in Mexico. Given the relative contrast between large-capacity technology and a small Mexican consumer market, the new machines did not diffuse widely and remained monopolized by a few firms. Yet three issues illustrate how these stories are more complex. First, in both cases the primary consumers were émigré entrepreneurs: Juan Brittingham, Antonio Basagoiti, and Ernesto Pugibet. These men were neither foreign investors nor Mexicans by birth. They (and indeed, a significantly large percentage of all late 19th century entrepreneurs and investors in the country) arrived with relatively modest resources, built their fortunes in Mexico, and had little or no intention of leaving (Cerutti, 1992; Haber, 1989, ch. 5; Hibino, 1992). We have, in other words, a particular social group that apparently exhibited behavior systematically different from that of many native-born Mexican elites. To explain the pattern of technology transfer across the Mexican economy—why transfer occurred in some industries and firms and not in others—we need to better understand the differences between these kinds of social groups. Were, for instance, these differences primarily cultural, a question of values and preferences? Or were they a matter of access to finance capital, family connections, or political favors?

Second, the political arena mattered. Mexico's patent system was the most relevant issue in the bottle and cigarette cases. Although by the late 19th century patent systems around the world had largely converged around a relatively homogeneous pattern, there remained significant differences (Beatty, 2001, ch. 4; Beatty, 2002). Mexican law offered patents to foreign inventors and their agents, did not place compulsory use restrictions on foreign patents, and left all adjudication of applications and conferred patents to the court system. The particular structure of the Mexican patent institution meant that entrepreneurs like Brittingham, Basagoiti, and Pugibet could obtain exclusive rights to foreign technologies. It also meant that the adjudication of disputes tended to favor the first to patent, regardless of technical considerations of novelty. In the cigarette industry, this apparently made possible Buen Tono's court victory over the rival Bonsack process in 1900. In the mining industry, it enabled the Mexican Gold & Silver Recovery Company to reestablish control over the cyanide process, even as its sister firms in the United States, South Africa, New Zealand, and Australia were losing control of the same patent rights due to a different set of patent institutions and political interests.

Third, we know little about the role of labor in the introduction of the automated bottle and cigarette machines, but it was likely to have been significant. In both of these industries, new automated machinery radically transformed labor relations, the nature of work, and presumably levels of employment. The contemporary experience of the textile industry is suggestive. The textile industry was Mexico's largest and most competitive, and leading firms wrestled over decisions to import automatic power looms repeatedly between the late 1890s and the 1920s (Gómez Galvarriato, 2000; Keremitsis, 1973). Although the relative cost of capital and labor in Mexico made the adoption of automatic looms marginally more expensive than in Britain and the United States, the difference was insufficient to explain firms' repeated decisions not to invest in the new technology. In the 1890s, the dominant factors appear to have been the cost of the skilled technicians necessary to maintain the installed looms, as well as the nature of consumer demand (automatic looms were more suitable for plain cloth than for fancy fabrics, and Mexican industry specialized in the later, relying on cheaper imports for the former). By the 1920s, however, it was labor's opposition to any labor-saving machinery in a post-revolutionary context that gave unions a greater political voice that doomed firms' efforts. By the 1920s, the political balance of social interests meant that costs, which might have been borne in the 1890s, were no longer tolerable. As a result, Mexico's textile industry retained 19th-century technology and, although it employed large numbers of relatively well-paid workers through the 20th century, the industry became increasingly uncompetitive internationally.

Attempts to modernize slaughterhouse technology further illustrate the importance of contextual factors in explaining the path of technology transfer (Pilcher, 1998). In the 1890s, a government study identified unsanitary food and water as accountable for one third of total mortality in Mexico City, and municipal officials pointed to the city's licensed slaughterhouses as one of the main culprits. In 1893, the Pauly Jail Company of St. Louis won the municipal contract to build a new slaughterhouse, and a state-of-the-art facility was complete by 1895. Its layout was based on U.S. models—an assembly line process replete with an overhead tram for moving the carcasses from the killing room to the loading docks. But problems plagued the new facility from the beginning. The tram frequently jammed; heavy doors, equipment, and cattle carcasses fell on workers, killing half a dozen in the first year alone; blood and gore failed to drain properly from the floor; and cattle suppliers complained vehemently. What had happened? Where had the link between the U.S. model factory and its replication in Mexico gone wrong? One puzzle concerns the technical replication of the U.S. model. Did problems arise from the incentives of the foreign contracting firm, from weak engineering skills of subcontractors in Mexico, from poorly transmitted engineering specifications or differing engineering cultures, or from inadequate supplies of intermediate materials and parts? A second puzzle involves the competing interests of cattle suppliers, municipal officials, building contractors, Mexican engineers, and urban meat vendors—all of whom appear in the documentation. The U.S. assembly line model was designed for a market where processed meat exited private slaughterhouses in refrigerated boxcars to be shipped to distant markets. In Mexico, the primary demand faced by officially licensed urban slaughterhouses was to supply fresh meat daily to local markets. There was intense pressure on the slaughterhouse managers to serve cattle suppliers equally, but the assembly line model gave first-comers preferential access to the city's meat vendors. This conflict between the design characteristics of imported technology and the particular structure of local economic and political interests resulted in failed innovation and the beginning of intense political negotiations over a modified system.

domestic technological capacity

A flood of foreign technologies swept Mexico between 1870 and 1910—a not uncommon experience for societies outside the North Atlantic in the latter half of the century. The consequences of this technological revolution were varied, as are the historical questions we can ask about the experience. Our interest here is one that extends well beyond historical cases and lies in the relationship between imported technologies and the capacity of the recipient society to be technologically creative. To what extent did imported machines and processes remain alien to the recipient society and its technological capabilities? In contrast, to what extent did individuals and groups in the recipient society assimilate imported hardware and know-how together with the interest and ability to continue innovating, independent of imported knowledge?

Part of the answer to such questions lies external to the process of technology transfer, in the nature of the recipient society: in social relations, the distribution of wealth and opportunity, the extent of technical education and basic literacy, and a wide range of related factors. But whether imported technology remained alien or was assimilated by the recipient society was also a function of the dynamic relations between the two. Three overlapping concepts capture essential elements. The first focuses our attention on linkages between imported technique and the domestic context. The conventional story of foreign technologies' role in 19th century Mexico highlights expanding global markets and the consequent spillover of advanced technologies from the North Atlantic (Wilkins, 1970). This view has tended to minimize the active participation of Mexicans. Historians have typically tied the resulting gap between imported technique and Mexican society to low levels of human capital or to the presence of cultural values that disparaged technical skills and discouraged innovation. We are left with a common assertion, often implicit, that technology transfer was wholly controlled by foreign investors and foreign engineers who "were loath to transfer it to any Mexican," while Mexicans proved uninterested or unable to engage foreign techniques (Adler Lomnitz & Perez-Lizaur, 1987; Beezley, 1987; Brown, 1993, p. 110). The result was isolated technologies, enclave activity, or *islands of modernity*. This was the case for the most visible foreign technologies: large-scale projects like railroad construction, oil extraction, electrical power projects, and public works (Guajardo, 1998; Kuntz Ficker, 1995; Kuntz Ficker & Connolly, 1999). In these activities, new technologies came to Mexico through direct investment by contracting firms based abroad that provided few links to Mexican society.

Isolation was not the only story, however. In contrast to technological enclaves with little impact on domestic capabilities, some imported technologies developed strong links to domestic society and stimulated local creativity and capabilities. The best known story here is the case of the glass industry in the northern industrial city of Monterrey (Haber, 1989; Hibino, 1992). There, the glass company established by Juan Brittingham after his acquisition of the Owens machinery provided the foundation for one of 20th century Mexico's most successful and innovative firms, the Vidriera Monterrey. Riding its success in the national glass bottle market, the company went on to develop its own research and development division, helped to sponsor the rapid expansion of technical education in the city, and within several decades was in a position to license its own innovations in glass technology to firms in the United States! Beyond this one case, however, we have few systematic studies.

The intimate relationship between imported technology and the recipient society—both economic and noneconomic linkages—shaped the potential for learning through each phase of the transfer process. Learning can take place through a wide number of venues, but is maximized through direct human interaction with the imported technology and foreign technicians. The problem in most cases, like Mexico's, is that there has generally been an inverse relationship between the presence of foreign technicians and the chance that local technicians and workers will work intimately with the imported technique. As we have seen, many foreign technologies in late 19th century Mexico were innovated and operated by imported technicians and, in some cases, with imported labor. This was especially common among large-scale infrastructure and public works technologies (railroads, the telegraph, electric power, port improvements, and urban public works) as well as with large-scale production machinery. Nearly all were installed and operated by foreign technicians, although more work is required to determine the extent of this practice.

A somewhat different form of learning is manifest in the third concept:

the ways that imported knowledge stimulated domestic invention and innovation. One kind of suggestive evidence for this demonstration effect can be found in the Mexican patent records. We have seen, for instance, how in the tobacco industry the technological story centered on the replacement of thousands of female cigarette rollers by new automated machinery in the 1890s. Here the story quickly became political as rival producers battled in the courts for control of patent rights and the winner—Buen Tono—went on to dominate the industry. Yet behind this conventional political story of court fights, political connections, and monopolization lie several other strands. The patent records, for instance, show that Buen Tono took over a dozen patents for cigarette machinery over the two decades following its acquisition of the Decouffle technology. Most of these apparently represent efforts to adapt, improve, and modify the original machine, and together they suggest an internal effort at research and development. Indeed, a preliminary analysis of a database constructed by the author of roughly 12,000 patents conferred in Mexico between 1850 and 1911 reveals several similar patterns across industries, as patenting by Mexican individuals, partnerships, and firms became ever more active through the 1890s and early 1900s. Like the Buen Tono example, many fields experienced streams of Mexican patents in the wake of the first appearance of a new foreign technology. This phenomenon is all the more suggestive; many of these fields were ones not typically associated with traditions of Mexican expertise: electrical processes (especially lighting), industrial chemicals, and precision instruments. Together, evidence like this suggests a relatively greater capacity for technical learning, and a relatively greater relationship between foreign technologies and domestic capabilities than has heretofore been asserted.

CONCLUDING REMARKS

Scholars have long been interested in the origins and determinants of technological change and recently have paid a great deal of attention to topics of international technology transfer and the social construction of technologies. Yet the literature on the former has often focused on postwar development issues or on a small number of 19th century success stories and colonial contexts. Nineteenth-century Mexico, the rest of Latin America, and many other settings have received less attention. Similarly, recent work on the social context typically focuses on change within a single society. The cross-cutting nature of technology offers a propitious opportunity to bring together the disparate currents of scholarly work on technology transfer and its social context.

Efforts to explain the wide range of historical (and contemporary) experiences of technology transfer should also lead us toward comparative studies. Our brief glimpse of the Mexican experience between 1870 and 1911 suggests two such possibilities. One would compare contrasting 19th-century cases of technology transfer and industrialization, including, for instance, Mexico, Russia, and Japan. All three imported large quantities of the same kinds of Western technologies through the second half of the century. Yet, by 1914 the industrial landscapes of each country varied, and their technological capabilities varied even more widely. The explanation for such disparity likely lies in a careful examination of political institutions and social elites in each country, but only a systematic comparison based on a common conceptual approach would suggest whether this was indeed the case. A second comparison might examine parallels between historical and contemporary experiences. Here again Mexico offers an instructive case. In many ways, Mexico in the late 19th and late 20th centuries exhibited similar trends. Both witnessed a rapid opening to international trade and foreign investment, supported by substantial institutional reforms (privatization of property rights, intellectual property reform, deregulation, and an increasingly open economy), and coupled with centralized government and some degree of increasing social inequality. Both periods also saw high levels of technology imports. As with 19th-century comparisons, a systematic comparison of these two eras might offer insights into the vexing problems surrounding technology transfer.

We know that stories of technology transfer are neither unilinear nor deterministic. Mexico, for instance, did not import and innovate all that was available abroad or even all that could have been profitably commercialized. Technological change and industrialization came slowly and incrementally, fraught with difficulties. Although some foreign technologies were innovated with little friction, many new projects produced a litany of complaints about obstacles to the acquisition, innovation, and diffusion of imported machines, parts, tools, and processes. For any given technology multiple paths competed, and those that emerged as dominant were contingent on the intimate relationship between the technology in question and the contextual dimension of the recipient environment. This relationship also conditioned the long-term consequences of imported technology on domestic technological capabilities in multiple ways: by displacing or suffocating domestic creativity, by creating a modern sector isolated from domestic society, or by enriching and stimulating domestic capabilities. In Mexico, we can observe each of these processes. To explain the varying experiences in any contemporary or historical setting we need to consider technology transfer in the context of economic markets, political institutions, and broader components of recipient society and culture.

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