From Imports to Innovation?
Foreign Technologies and "Technological Capabilities" in Mexico, 1870-1910

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New technologies poured into Mexico in the decades after 1870, as they did throughout Latin America and the world beyond the North Atlantic. Across urban and rural landscapes, Mexicans increasingly substituted new machines, processes, tools and products for traditional ones: railroads for mules, reinforced cement for stone, beer for pulque, ready-made for home stitched clothing, inanimate for animate power, and mass-produced made-in-Mexico products for what was previously hand made and imported. Technological change was nearly ubiquitous; it was not, however, universal, uncontested, or unilinear. While some activities and places witnessed profound and rapid transformation, in others traditional methods proved more enduring. In Mexico, most contemporary observers believed that the 'technology gap' and thus Mexican *atraso* (backwardness) could be overcome simply by importing new machines and processes. This proved not to be the case. Technology imports could and did countribute to short term economic growth; they did not generate a longer term development of domestic technological capabilities. This project examines patterns of technological change in Mexico and situates this case within the global question: why are some nations better able than others at turning early technology imports into a domestic capacity for the sustained production of locally adapted innovations?

Mexico 1870-1910 provides an ideal frame for this study.[1] Before roughly 1870 Mexico was a region of isolated and localized markets and identities without an effective national market or polity. Productive technologies differed little from those used in the late eighteenth century, with few exceptions. Yet by 1900 business was generally conducted within national and international markets. Throughout this era new ideas embodied in machines, people, and print poured into Mexico from the United States and Europe. They altered both production and people's lives by substituting mechanical methods for what had previously been home-made, hand-made, 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, in commercial agriculture. New technologies altered not only the nature and scale of production but the lives of Mexicans who found work in new industries, who consumed the products of new factories, and whose lives were affected in less direct ways. Technological change created new opportunities while also undermining traditional patterns of consumption, labor, and production. All this constituted the decisive and often socially dislocative beginnings of Mexico's material modernization that did not end with the revolution of 1910; the distinct patterns of technological change in this era continued to the political and economic transitions of 1929 and fundamentally shaped Mexico's twentieth century development path.[2]

North Atlantic countries like Britain, the US, France and Germany experienced waves of technological change over the long nineteenth century—what we have long called the first and second industrial revolutions. New ideas, tools, machines, and methods emerged from and contributed to dramatic economic as well as social and cultural transformations. Productivity-

[1] Historians generally agree that the critical economic and political foundations of Mexican modernization appeared in the 1860s and 70s, pre-dating the onset of the dictatorship of Porfirio Díaz (the "Porfiriato," 1876-1910). On the economic transition, see Cárdenas, 1997; Marichal, 1997; Haber, 1989; and Beatty, 2001 and 2002. On the political (and cultural) transition, see Pani, 2001 and Lomnitz, 2001, among others.

[2] Gómez-Galvarriato, 1998; Musacchio et al., 2008; Haber et al., 2003.

enhancing advances originating in western Europe and the United States spread globally through rapidly expanding volumes of trade and direct investment, and through imposed colonial relations. This was a world divided between technology exporters and technology importers. Global flows were part imperialist project, part spill-over from industrial growth in Europe and the US, and part the efforts of elites in nations as diverse as Norway, Russia, Japan, Brazil, Australia, and Mexico to emulate the experience of the rapidly industrializing nations of the North Atlantic. Yet the impact of imported technologies varied dramatically across the globe.[3]

We know that imported technologies began to fundamentally transform socio-economic landscapes in Mexico and elsewhere in the second half of the nineteenth century. We also know, however, that imported ideas and enhanced productive output do not necessarily yield effective *technology transfer*, understood as the development of *domestic technological capabilities*—a local capacity to absorb, adapt, utilize, and independently innovate technological change.[4] Remarkably, however, there has been virtually no systematic work on technological change in Mexican history, and relatively little for Latin America. This is especially true for the nineteenth century, paradoxically one of the most studied eras of technological change on both sides of the North Atlantic.[5] This paper presents a preliminary discussion of the last chapter of my current book project. The book begins by tracing the broad contours of technological change across the Mexican landscape between 1870 and 1929, examining its extent and its relationship with

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[3] Compare, for instance, Norway (Bruland, 1989) and Japan (e.g. Nicholas, 2009; Morris-Suzuki, 1994) with formal colonial contexts (e.g. Headrick, 1988). Latin America fell between. On technological change in the North Atlantic, see Landes, 1969, and Mokyr, 1990 among many others.

[4] See below for further discussion.

[5] For anecdotal references, see Villareal, 1985; Barragán and Cerutti, 1993; Hibino, 1992; Carrillo Rojas, 1998; Haber, 1989; Gómez-Galvarriato, 2000; Gutiérrez Alvarez, 2000; Marichal and Cerutti, 1997; Velasco Avila et al., 1988; Kuntz and Riguzzi, 1996; Bernstein, 1965; Rosenzweig, 1965; Guajardo, 1998; Saragoza, 1988; Pilcher, 2006; Cerutti, 1992; and Brown, 1993. For excellent broader studies, see Sánchez Flores, 1980; Tortolero Villaseñor, 1995; Corona Treviño, 2004; and Concha and Calleros, 1996. Note technology's complete absence in recent Anglophone scholarship, including: Bulmer-Thomas, 1994; Haber, 1997; Coatsworth and Taylor, 1998; as well as in Dobado et al., 2007. In contrast, the *Memorias del segundo congreso de historia económica*, 2004, at www.economia.unam.mx/amhe/memoria/memoria.html includes many technology studies.

existing practice. The central core presents three case studies that capture broad patterns; these chapters are briefly summarized here. The book then works to explain the contours of change by examining the contextual factors that facilitated or constrained the adoption, innovation, and diffusion of new ideas and new techniques. Context is central, as technological change is intimately embedded within a network of linkages and interactions with the broader social, political, cultural, technical, and economic environment. Finally—and in preliminary form in this paper—the book will explore the relationship between imported know-how and Mexico's domestic capacity to generate technological innovation. It thus addresses the central paradox of technological change in early modernizing Mexico: the contrast between a virtual tidal wave of technology imports—adopted, innovated, and sometimes widely diffused—yet an enduring dependence on foreign know-how and hardware.

Mexican Technology Imports 1870-1910: A Very Brief Outline

New technologies poured into Mexico beginning in the 1870s, part and parcel of an era of rapid globalization in trade and investment. Just as "technologies" are not simply physical artifacts, but rather a complex that embodies scientific and technical knowledge (both codified and tacit), accumulated skills, and forms of organization (as well as the physical hardware of machinery, parts and tools), the late nineteenth century global trade in technology included flows of (1) hardware, (2) print materials, and (3) people.

Between 1870-1910 Mexico imported over $230,000,000 US dollars worth of technical hardware. We can quantify this vast import flow using the commercial records of Mexico and her largest trading partners, and we can begin to disaggregate it by economic sector, industry, and particular technology.[6] By 1910 capital equipment imports were eight times their 1870 level, having grown faster than any other import category, nearly 50% faster than annual GDP growth to constitute a "sustained process of capitalization."[7] Manufacturing machines captured roughly 40% of the total, mining equipment 28%, while agriculture received less than 5%.

At the same time, volumes of print material containing codified technical information came to Mexico in the form of blueprints, technical journals and papers, textbooks, sales catalogues, and patent specifications. These accumulated in libraries of government ministries and organized societies, in schools and universities, in private homes, in the offices of commercial and manufacturing companies, and on the shelves of bookstores and hardware retailers in every Mexican city. Patent records provide by far the largest and most easily examined source of imported knowledge embodied in print, captured here in a database of roughly 15,000 Mexican patents.[8] Overall, patenting in Mexico expanded at an average 13% per year through the period. While Mexican inventors took 50% of all patents before 1880, they took just 20% thereafter as patenting by foreigners grew rapidly. Patenting was strongly procycle, closely matching short term movements in Mexican economic indicators and distributed across sectors in close correlation with the direction of productive investment.

Finally, by 1905 or so over 20,000 foreigners lived and worked in Mexico. Many of these—over 50%--carried with them specialized technical information—accumulated skills and

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[6] Data collected from United States, Commerce and Navigation of the United States, various years 1870-1910; Great Britain, Annual Statement of the Trade and Navigation of the United Kingdom, various years 1870-1910. The data collected and examined here is my own, but should be compared with similar work by Sandra Kuntz Ficker, "Imports" and Comercio exterior; and Haber, Razo, and Maurer, Politics. A comparison with the most systematic recent work (Kuntz Ficker) shows some relatively minor differences in trend and relative levels. Most importantly, the criteria for inclusion in the aggregate series that I use here is broader than that used by Kuntz Ficker.

[7] For comparative studies, see Tafunell, "Capital Formation," Hofman and Ducoing, "Capital Goods," and Pineda, "Financing Manufacturing."

[8] Neither the national archive or the Mexican Patent Office (IMPI) contain records of even fifty percent of all patents issued before 1910. This database is built from three sources: the AGN holdings, daily issues of the *Diario Oficial* (before 1903), and monthly issues of the *Gaceta de Patentes* (afte r1903), drawn from the Hemeroteca Nacional, the library of the AGN, the library of the US Patent Office, the Boston Public Library, and the Regenstein Library at the University of Chicago.

expertise and tacit knowledge. A large percentage of these were technically skilled, as engineers, technicians, mechanics, skilled workers, managers and entrepreneurs. Although most visible in mining, railroads, utilities, and in the American, Spanish, and French colonies of Mexico City and elsewhere, they comprised the backbone of the Porfirian technical elite. Many—most—of these were in Mexico on relatively short term work assignments, to gain experience, or to build a business before retiring to the US. Some percentage, however, built long-term careers in Mexico, closely integrated in the local society and economy, reinvesting profits, and raising families. Chapter 3 examines these three venues for technology imports in detail, using them to map the rate, level, and direction of technological change.

Three Case Studies

The central core of this book project presents three case studies in chapters 4-6, each representing one broad type of technology that was commercialized in Mexico.[9] Each case reconstructs a detailed narrative story from primary evidence that centers more on the web of interactions between innovation and Mexico's contextual environment than on the technical artifact itself, beginning with the broader social and economic context. In each case, the introduction of new techniques undermined the existing technological system and transformed not only production but also the lives of workers and local cultures of consumption.

Sewing machines represent a multitude of small scale, multi-purpose, product technologies that were imported in large numbers and that typically diffused fairly widely

[9] Although these three types capture a large share of new technologies in 19th century Mexico, they do not capture all. Most importantly, railroads, public works, and utilities contain patterns of change that are not captured well here. However, these three cases and types do capture the majority of discrete technologies—in machines and know-how—imported in Porfirian Mexico.

through the Mexican economy.[10] Like steam engines, pumps, some agricultural implements, and diverse tools, sewing machines were marketed by foreign manufacturers and distributors, sometimes handled by local retailers, and were "consumed" as products (and subsequently used as production technologies) by thousands of households and dozens of companies through the country. By 1910, firms like Singer and others had imported over 300,000 sewing machines; roughly 70% went to households in Mexico's cities and rural villages while the rest were installed in sweatshops and new clothing factories.

The second case represents large-scale, single purpose factory technologies (or technological systems). Between 1903 and 1907 each one of Mexico's four or five largest breweries tried to acquire newly developed technology to automatically manufacture glass bottles, centered on the Owens machine from Toledo, Ohio.[11] A growing preference for beer over pulque drove demand, while existing artisanal bottle production could not keep up. Despite early acquisition of the Owens rights by a Chihuahua-Torreón investment group, successful commercialization of the new system would elude persistent efforts for nearly a decade. Multiple obstacles stood in the way, including access to key complementary information, the location of appropriate supply markets, political institutions, regional rivalries, and the technical appropriateness of the system to its new environment. Most obstacles proved relatively malleable rather than obdurate, however, and the innovating firm went on to become one of Mexico's most innovative.

[10] The sewing machine story is based on research in the Singer Company archives at the Wisconsin State Historical Society; Federal inspectors reports in the AGN, Departamento de Trabajo; and extensive work in a range of Mexican newspapers, including *Diario del Hogar, Siglo Diez y Nueve, El Imparcial, El País, El Tiempo, El Monitor Republicano, El Universal*, *El Economista Mexicano*, and the *Boletín de Instrucción Pública*.

[11] The Owens-in-Mexico story is built from research in the Toledo Glass Company papers at the University of Toledo and the Brittingam archive at the Universidad Iberoamericana-La Laguna, complemented by documents in the AGN, Condumex, and the newspapers cited above.

The final case represents new processes not embodied in a hardware package, typically new chemical processes or new organizations of production. By the 1870s, Mexican precious metal mining was in a growing crisis. Like its counterparts around the world, easily accessed, metal-rich, and easily refined bonanzas had become fewer and farther between. Annual profitability increasingly depended on processing deeply buried, low-value ores. Variants on the mercury amalgamation process—the dominant technological system in precious metal refining for over three centuries—were not up to the challenge. Among several competing new systems, the use of cyanide to separate gold quickly diffused in world mining centers.[12] In Mexico, the process was introduced quickly but adopted slowly. Crucial here was its adaptation to silver, and here Mexican mines proved to be world leaders in innovation. Driven by US investment and coupled with the development of complementary technologies, cyaniding quickly diffused through Mexican mining districts once adaptation was accomplished.

The introduction of sewing machines, the Owens system, and the cyanide process yielded significant productivity gains and hence contributed in the short term to Porfirian economic growth. Similar stories played out with a wide range of other technologies, although failures (or sharply constrained productivity) were not uncommon. Chapter 7 examines patterns in the the extent of and limits to the importation, commercialization, and diffusion of new technologies.

Technological Capacities

The book's final chapter will examine the relationship between technology imports and Mexico's "technological capabilities." It begins by discussing the relevant concepts

[12] The cyanide story in Mexico is built primarily on mining trade journals (most published in the US), Mexican commercial papers, the special collections at the Bancroft (UC Berkeley) and Benson (UT Austin) libraries.

(summarized below), drawing on literature from development economics and work on the social construction of technology. It then turns to a preliminary survey of the evidence.

A. Concepts

For countries outside the North Atlantic in the nineteenth century, the prospect of simply borrowing new machines and tools from the earlier industrializers seemed quicker and easier than investing in the slow, expensive, and uncertain process of invention. Economists have long agreed, and neo-classical theory has typically viewed technology—new ideas—as a public good that can flow between users and between countries easily, with little friction, or low transaction costs.[13] As a result, went the implicit assumption, the nineteenth century wave of technological creativity and innovation in the North Atlantic provided a backlog of new technologies (a "global stock of knowledge") from which newly industrializing countries could readily pick and choose. Outside the North Atlantic, countries would simply reap the global technological spillover without bearing the substantial costs of research and development.

Economic historians of nineteenth century industrialization have often embraced this view, arguing that the ability of relatively late industrializers to borrow the technology of more technologically advanced countries provided a means to catch-up to the industrialized nations. Borrowing new technologies would result in relatively faster rates of productivity growth and thus provided a means for convergence. From Alexander Gerschenkron (1962) to Sidney Pollard (1981) and Robert Allen (2009), many have argued that less industrialized countries should be able to quickly catch up to the earlier industrializers by embracing and importing new

[13] Nelson, 1987; Lall, "Technological Capabilities," p. 165. David, "Intellectual Property."

technologies.[14] For economic and political elites in countries like Mexico in the nineteenth century, "convergence" translated as "*progreso material*" and attaining the economic wealth, cultural prestige, and political independence (de facto or de jure) enjoyed by countries like England, the United States, France, or Germany.[15] Although the language and labels differed, these concepts are not anachronistic.

However, reality did not often conform to theory or desire. While some countries have built economic growth, industrial development, and sustained technological creativity on imported technology, most have not, despite roughly similar access to new technologies and knowledge in the international market.[16] More than a century of mass migrations and massive global trade in machines and knowledge has not yielded a globally balanced distribution of growth, wealth, and welfare. This was true for many in the late nineteenth century as it has been for much of the post-colonial world in the second half of the twentieth.[17] Observing development disparities, scholars have increasingly argued that multiple obstacles stand between technology imports, economic growth, and mastering new technological knowledge and capabilities. If the productive use of imported technologies is difficult, and if the assimilation of

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[14] Gerschenkron, Economic Backwardness;" Pollard, Peaceful Conquest, p. 142: once new technologies are adopted, "nothing appeared to be able to prevent the region concerned from 'taking off'." Allen, British Industrial Revolution, pp. 154-155: "The low wage country finds that it pays to leap over many stages of technological development and go directly…to the latest…technology. Catch-up is very rapid—a great spurt. The Industrial Revolution spreads around the globe." On "catch-up" and "convergence" there is a large literature; see among many others Abromovitz, "Catching-up."

[15] From Japan to Mexico, contemporary rhetoric to this effect was extensive. In Mexico, it frequently took the form of references to "atraso" or to a "tributary" status, often viewed through a social Darwinistic vision of international competition and threats. See Weiner, "Battle for Survival," and Beatty, "*Riqueza*."

[16] Not all countries have similar access to international technologies, due to conditions of colonial status or to self-imposed trade polices. For a sample of the extensive literature on the implications of closed (protectionist) and open (free trade) economies for innovation and technological change, see Krueger, "Policy Lessons;" Grossman and Helpman, "Innovation and Growth."

[17] On the difficult nature of the third (and fourth) waves of international technology transfer, see Strassman, Technological Change, ch. 8; Nelson, "Technological Capabilities;" Jeremy, "Introduction;" and Bruland, "Norwegian." On varying nineteenth century colonial contexts, see Headrick, Tentacles; and Todd, Colonial Technology. On Meiji Japan, see Uchida, "Transfer"; Bernstein, "Toyoda;" and Morris-Suzuki, Technological Transformation. On the more recent East Asian experience, see Amsden, Rise of 'the Rest', and Kim, Imitation.

new knowledge and know-how is even more so, then there is little chance that knowledge imports will enhance the innovative potential of the importing country. The historical record suggests that a country's ability to catch-up is contingent on its ability to first adopt and use foreign technologies and then to more fully assimilate new knowledge, and that these abilities are historically rare.

Why are some nations better able than others at turning early technology imports into a domestic capacity for the sustained production of locally adapted innovations? What shapes a country's ability to use and assimilate new knowledge? *Technological capacity* (or *capabilities*) refers to the capacity to not only adopt and use imported technologies, but to assimilate the associated knowledge to a degree that permits repair, modification, improvement, and that can stimulate a broader and sustained process of creative invention and innovation in response to changing conditions and new opportunities.[18] Figure 1 (at end of paper) maps the elements of a process that begins with *technology imports* and ends, perhaps, with *technology transfer*.

In the short term, the adoption and use of foreign technologies typically requires more than simply acquiring a machine or blueprint, picking it off a global shelf and installing it in the importing country. Potential challenges and obstacles are multiple. Turn-key operations are the exception rather than the rule. Some level of technological knowledge and experience with the particular new technique or similar machines, processes, tools, and systems is typically required. Moreover, the activities of acquisition, installation, and operation typically require substantial research, information gathering, feasibility studies, and management skills. Failures are

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[18] The following paragraphs draw from Lall, "Technological Capabilities;" Keller, "Absorptive Capacity;" Solo, "Capacity to Assimilate;" Kim, Imitation; Fransman and King, Technological Capability; Ho Koo and Perkins, Social Capability; Jeremy, International; Strassman, Technological Change. Both Lall and Kim idenfity *investment* and *production* capabilities, together with *linkage* capabilities (Lall) and *innovation* capabilities (Kim).

common, and often installed processes run below optimal efficiency. Access to technical expertise is often essential to the use of imported technologies.

In the longer term, commercializing new technologies does not necessarily require a local capacity to operate, trouble-shoot, repair, modify, adapt, and improve imported machines and processes, nor does it necessarily contribute to the creative, innovational capacity of individuals and organizations within local society. The second layer of technological capacity is the ability of individuals and organizations to absorb, assimilate, and otherwise internalize new know-how, and especially to learn from it, thus enhancing a nation's technological capabilities.[19]

Technology Transfer is thus more than simply importing and commercializing foreign machines and processes, or passively transferring something from one place to another. It involves the use of technological capabilities to introduce new technologies developed abroad, to adapt them to local conditions, to operate them efficiently, and ultimately to assimilate the skills and knowledge embodied in the technology, thus enhancing local capabilities.[20]

Technology transfer is thus a dynamic process in which learning (assimilating new knowledge) is a central component.[21] Whether technology imports generate learning—and the extent of learning that takes place—is a function of two factors. First, the capacity of an

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[19] The ability to master and assimilate new knowledge has often been labeled "*absorptive capacity*." The concept was developed primarily to explain the differential capacity of firms to assimilate and exploit external knowledge; see Cohen and Levinthal, "Absorptive Capacity;" Criscuolo and Narula, "Novel Approach." On the application of the concept to societal capacities, see Kim, "Absorptive Capacity;" Keller, "Absorptive capacity." Many studies of "technological capacity" include this sense of "mastery of knowledge" to support adaptation and commercialization as well as the more general sense of "technological creativity" (see below); for instance Solo, "Capacity to Assimilate;" Lall, "Technological Capabilities." For a very early application to post-war Latin America, see Strassman, Technological Change, ch. 8; also Wilkins, 1974.

[20] "Technology transfer" is sometimes used broadly to denote any cross-border (or even inter-firm) movement of machines, tools, and processes, while narrower (and more common) usage denotes the assimilation of sufficient know-how and expertise to operate, trouble-shoot, repair, modify, and adapt the technology. Here I use "technology imports" for the former and "technological capacity" for the latter. See also Rosenberg, 1970 and 1982; Ruttan and Hayami, 1973; Fransman & King, Kim, 1997; 1984; Jeremy, 1991; Ho Koo, 1995, and Katz, 1987.

[21] The following paragraphs draw generally from the literature on technological capabilities, absorptive capacity, and technological learning cited here. See especially Kim, "Absorptive Capacity;" Nelson, 1990, esp. pp. 78-79; Amsden, 2001; Fransman & King, 1984; Mokyr, 1990; Villavicencio & Arvantitis, 1994.

individual, group, or society to use, adapt, and assimilate technology-based knowledge is shaped—at any moment in time—by its level *human capital*.[22] This is a broadly defined assessment that includes conventional measures like the level and quality of basic education, measured by school attendance or literacy; the extent of technical skills and know-how acquired on the job; the extent and quality of scientific and technical education, including basic scientific education, applied engineering programs, and research and development activities; the existance of informal training programs and apprenticeships; the size and nature of scientific communities, especially manifest in formal societies and organizations that facilitate study and exchange; and the cumulative experience of doing—of working with particular technologies across economic activities. What matters is the relative level and nature of human capital in the importing country and in the exporting country—in other words, the "technology gap." If (hypothetically) the gap is nonexistent, then obstacles to learning and to the adoption and use of new technologies are likely minimal, and the assimilation of newly developed ideas easy. If, in contrast, the gap is large, then local use and adaptation will be difficult, will more likely require foreign expertise, and the local assimilation of new knowledge—learning—looms both more difficult and, in the long run, more important.

Second, then, the potential for local learning and thus effecive technology transfer is enhanced by the quantity and quality of *interactions* between imported know-how and the importing society. Opportunities for interaction make learning possible; without interaction, little learning can happen and imported technologies remain enclaves with little impact on the local capabilities. Interactions can take many forms, and can be centered around individuals, organizations, and social groups. Interaction between imported technologies and local actors

[22] On human capital, or the "knowledge base," see Solo, "Capacity to Assimilate;" Lall, "Technological Capabilities;" and Kim, "Absorptive Capacities;" among others.

include activities required to adopt, adapt, commercialize, and repair new technologies; interactions with external manufacturers, suppliers, and technicians; and the activity of operating and maintaining the technology itself. Commercializing imported machines can yield learning-by-doing and, perhaps, possibilities for reverse engineering (or at least for first-hand observation and learning-by-seeing). Imported blueprints, patents, trade journals and even sales catalogues provide new sources of technical information and arms-length interaction with communities of foreign suppliers and innovators. Knowledge embodied in immigrant workers and engineers can contribute more directly to interpersonal instruction, interaction, and learning. The same holds true for young national technicians sent abroad for education and training, as long as they return to apply their new knowledge at home. Human engagement with forms of imported knowledge is critical, and learning is maximized by the range of human actors who have the opportunity for meaningful interaction.

B. Evidence

What follows is a preliminary discussion of evidence from our three cases and other examples that speak to the relationship between imported technology (both hardware and know-how) and Mexico's "domestic technological capabilities." There is little to count here. By its nature, most of the issues lie amid more qualitative kinds of evidence, and this discussion is thus more exploratory and speculative than descriptive or analytical, drawing partly from case studies and partly from a wider range of secondary works. Its goal is to identify a range of issues relevant to our central questions and to indicate directions for further research. This section examines five issues that played critical roles in the relationship between imported technologies and local technological capabilities in late nineteenth century Mexico. First, how big was the technology gap—the distance between the knowledge embedded within imported technologies and existing practice (know-how, including both human capital and skills) in Mexico? Second, what was the state of technical education during the Porfiriato, and to what degree did it provide a foundation for engaging with and learning from imported technologies? Third, what was the nature of interactions between local actors and imported technologies, in the absence of which enclaves dominate and little learning occurs. Fourth, to what degree did individuals, groups, and organizations provide venues for interaction, for learning, and for information gathering and exchange in Porfirian Mexico? Finally, did government policies go beyond supporting technical education to promote not just the importation of foreign capital and machines, but to support local learning and domestic—Mexican—capabilities?

A. Technology Gap

Machines, processes, and other forms of new technologies imported by Mexico typically presented a large disjuncture with existing practice. Indeed, this was exactly what advocates sought: to acquire the most advanced machines and ideas possible—*lo más moderno*—taking advantage of their expanded productive capacity while avoiding the cost and uncertainty of local research, development, and invention. Sewing machines, the Owens bottle machine, and the cyanide process (for instance) all represented a substantial, nearly overnight jump from artisanal to fully mechanized production. So to did new machines, processes, and systems in other industrial settings as well as in construction, public works and utilities, transportation and communications, and in some branches of commercial agriculture.[23]

[23] Not all newly imported technologies represented such a sharp disjuncture from previous practice. Many tools and implements, for instance, used new materials but represented only modest design changes.

Imported technologies often presented a level of technical knowledge and machine construction skills that were not present in late nineteenth century Mexico's inherited human capital foundation. Just how large was this gap? None of our three case study technologies lay within reach of the technological capabilities of local technicians and workers. Sewing machines could be operated, but not easily repaired, modified or replicated. The Owens machine eventually proved an exception, but required over two decades of dependence on foreign know-how to operate, modify, and improve before the Compañía Vidriera was able to internalize the capacity to provide those services locally. The cyanide process lay out of reach of Mexican mining engineers, partly because of its technical, informational, and financial requisites, and partly because of the near-complete monopolization of technical positions by US engineers. Other new technologies lay even further beyond the reach of existing science and technological capabilities in Mexico. From electricity to chemistry to metallurgy, there was no institutional base nor critical mass of trained individuals who could assimilate, translate, and reproduce new technologies that were emerging out of new scientific milieus abroad.

This was both a *knowledge* gap as well as a *know-how* gap. The most acute aspect of the latter lay in domestic metal working, metallurgical, and machine tool capacities in Mexico. Although it was not the case, as some historians have asserted, that there was no iron foundry and metal working capacity in the nineteenth century, neither was it a thriving sector. In late century it remained primarily artisanal, with little ability to replicate global frontier machinery for local homes, workshops, mines, and factories.[24] Although individual scientists, engineers, and inventors could construct single-unit models in their laboratories and workshops, there was

[24] The only significant exception to this was the Fundición de Sinaloa, in Mazatlán, which produced hundreds of steam engines and boilers through the 1880s and 1890s. It, however, was dependent on government subsidies for survival. See Carrillo Rojas, Los caballos de vapor and Avilas Galán, "A todo vapor." More research on the range of iron foundries, metal working establishments, and machine skills in Porfirian Mexico is needed.

no domestic capacity to produce machines for sale and productive use.[25] Nearly every newly imported technology was accompanied by foreign expertise to install, operate, trouble-shoot, and repair; few, moreover, could be replicated and manufactured in Mexico.

B. Technical Education

Porfirian officials were conscious of the gap between Mexico's technical knowledge and that abroad.[26] This understanding drove policies that created extremely favorable conditions for the importation of foreign capital, goods, and know-how. It also motivated new investments in technical education at home. Education can enhance local abilities to engage and learn from new technologies at four levels: basic primary education, basic technical education, and engineering training.[27] Porfirian educational reforms sought to do exactly this. Let us examine each in turn.

Basic literacy remained constrained despite a modest expansion during the Porfiriato. National literacy rates at the turn of the century were likely not much above twenty percent, compared to nearly ninety percent for the UK, US, and other North Atlantic societies.[28] Primary school enrollment rates tell the same story. In Mexico, there were about 550 enrolled for every 10,000 population, representing 27% of the US level and 38% of the British.[29] A school enrollment gap relatively smaller than the literacy gap suggests that enrollment figures in Mexico masked some combination of low actual attendance and low quality education. This data, however, somewhat overstates the context in which most new technologies were introduced in

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[25] See, e.g., the sewing machine constructed by Leandro Ramírez; Tenorio, World's Fairs, p. 134, over a half century before the first mass produced machines in the country (Banco de México, Directorio de Empresas, p. 255.
[26] Beatty, "*Riqueza*."
[27] I have left out science education, especially basic science, as beyond the scope of this study. On science in Porfirian Mexico, see Trabulse, Historia de la ciencia. More research on the relationship between science and technology during this period is needed.
[28] INEGI, Estadísticas. For the US, see HSUS, 1960, H-407; for the UK, see Mokyr, Economics of the Industrial Revolution. See also Mariscal and Sokoloff, 2000 for a superb study of 19th century schooling in the Americas.
[29] Easterlin, "Why," appendix.

Porfirian Mexico. Literacy levels in urban areas and among the tens of thousands who found work in the modern industrial sector lay significantly higher. In those districts like Orizaba, Rio Blanco, and Santa Rosa where the majority of the population worked in modern textile factories, for instance, illiteracy ran between 50-60%, about the same as in the artisanal sector about mid-century.[30] Though still well below North Atlantic standards, this was sufficient to support a thriving set of penny-press newspapers for workers.[31] Although basic literacy likely made relatively little difference for common workers' ability to work with new technologies, there is evidence that literacy aided workers' upward mobility within firms and, occasionally, moving between firms. Upward mobility often brought with it increased interaction with the technology of production in more highly skilled and responsible positions.[32]

The Porfirian state also sought to promote technical education at both basic and advanced levels.[33] This began with the *Escuelas de Artes y Oficios*. Restructured in 1892 to improve technical instruction for workers, the schools sought to provide the "*principal elemento del progreso de los grupos industriales*."[34] Geared to workers, with most courses offered at night and tuition paid by the state, the schools' curriculum featured introductory training in basic mechanical principles and skills. A handful of states supported similar programs. In Guerrero, for instance, the schools offered training in the *"manejo y uso y mecanismo de las herramientas y máquinas más esenciales de cada oficio, industria o trabajo a que se dediquen los obreros*."[35]

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[30] INEGI, Estadísticas.
[31] Gómez-Galvarriato, "Revolution," ch. 3.
[32] Gómez-Galvarriato, "Revolution," ch. 2. On upward mobility among workers immediately following the Revolution, see Keesing, "69, p. 729.
[33] The following paragraphs are based on the work of Mílada Bazant unless otherwise noted. See especially Historia de la educación, especially chapter V, "Alfabetización y preparación de técnicos;" and "La enseñanza." There remains a wide field for historical research on Porfirian education, especially in applied science and engineering.
[34] Bazant, "Alfabetización," p. 116.
[35] Bazant, "Alfabetización," p. 108. The curriculum varied by school and era, but typically included, for instance, instruction in "carpintería, tornería, ajuste, herrería, fundición, pintura y escultura decorativa" as well as in mechanical and electrical work; p. 115. Despite increased emphasis on practical education and training, there

Most complemented classroom instruction with hands-on training in workshops, sometimes also with apprenticeship opportunities. Many also offered English classes to facilitate employment by foreign firms. Technical training programs also targeted women who increasing found work in some lines of new industrial labor.[36]

Federal and state support had, by 1910, established 46 such schools in Mexico City (enrolling about 5,350 students) and 128 schools distributed through the states, although enrollment numbers for the state programs barely sum to the Federal program. Moreover, enrollment levels masked much lower attendence and graduation rates, which lay at just 25% or less of initial enrollment, despite the frequent inducement of free food and clothing. Fewer than 5,000 workers completed training through the adult schools, a number representing no more than 0.1% of the labor force and just 0.6% of modern sector workers.[37] Likewise, the *Escuela Práctica de Maquinistas* (incorporated into the Escuela de Artes y Oficios in 1896) sought to train Mexican workers to replace foreign technicians, but also enrolled and graduated only small numbers. In other words, the results of government efforts to promote basic technical training were insignificant at a national level.

In the *Colegio de Minería*, founded in 1792, Mexico boasted the oldest and most distinguished institution of advanced technical education in Latin America. Major reform in 1867 produced the *Escuela Nacional de Ingenieros*, still housed in the Palacio de Minería, now

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continued to be complaints that technical education remained too theoretic for Mexican workers interested in practical application of new skills; p. 116.

[36] The ratio of women in occupational training programs to women in the modern work force appears significantly larger than that for men: in 1900 there were about 5,800 seamstresses and 990 female factory workers in the Federal District; by 1910 nearly 2,000 women had enrolled in occupational education programs. Bazant, "Alfabetización," Anexo 1.

[37] On the numbers, see Bazant, "Alfabetización," Anexo 1, and also pp. 110, 112. The labor force calculated in 1895 at about 4.5 million, of which about 17% worked in the modern sector (manufacturing, mining, transportation, and construction).

offering degrees in civil, mining, and mechanical engineering.[38] However, as with the Escuelas de Artes y Oficios, these engineering programs received many inquiries, but enrolled few and graduated only a relative handful.[39] Annual graduates averaged only about 13, the majority of them topographical engineers, trained in mapping and not in the applied work of civil, mechanical, electrical, or metallurgical engineers. Between 1876 and 1910, the school graduated only 448 engineers. A number of states also supported engineering programs, but also with sparse results. Some closed for lack of funds, others for lack of pupils.

The *Escuela Nacional de Agricultura* also sought to educate, train, and produce engineers and technicians capable of introducing the latest advances in irrigation, fertilizers, seed and breed selection, and machinery to commercial agriculture.[40] In addition to the advanced agricultural curriculum, it also published a gacette, many pamphlets on new methods, and agricultural science textbooks in Spanish. However, like the other engineering programs, the agricultural school only produced a small number of graduates: not more than several hundred over thirty five years, while several state programs closed due to lack of students. Promising reforms to the program and the addition of extention and experimentation stations in the last years of the Porfiriato were too little, too late. The founding vision of producing a new generation of technicians who could work to transform productivity of Mexican export and food agriculture proved a failure. Likewise, the *Colegio Militar* trained military officers in technical subjects, especially artillery and fields related to civil and mechanical engineering. As with the other schools, its curriculum underwent substantial reform during the Porfiriato, upgrading standards

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[38] Within these fields, specific course work included *arquitecto, ensayador, apartador, topógrafo, caminos, puertos, canales, telegrafista, industrial,* and *electricista* (after 1889). In 1902 the field of metallurgical engineering was added. Bazant, Historia, p. 241-242.

[39] On the numbers, see Bazant, Historia, p. 243 and "La enseñanza," Anexo 1.

[40] In addition to Bazant, Historia, pp. 248-253, see the superb work of Tortolero Villaseñor, de la coa; also Zuleta, "Fomento de la agricultura."

and promoting more practical education and training. Also like the other schools, however, the impact on military capabilities and technical expertise was limited to just a small core of newly professionalized officers.[41]

Why did efforts to promote engineering education yield so few results? Answering this question lies beyond the scope of this project. Despite superb work on technical engineering by several historians (especially Mílada Bazant and Alejandro Tortelero Villaseñor), we can still only suggest several hypotheses for future research: First, the Mexican schools offered a curriculum inappropriate for the new, late nineteenth century wave of global technological change. Many in fact criticized Mexico's curriculum as too theoretic, with insufficient emphasis on practice and application—despite substantial efforts to increase the practical component in all fields through the Porfiriato. Second, the financial resources allocated by the state to technical education were insufficient to support an effort of greater scale and scope. This would begin with greater funding at the primary and secondary levels to funnel students towards technical careers, as well as funding for extential and experimental stations located in the field. These only appeared at the very end of the Porfiriato.[42] Third, there was little public interest in technical education; demand was weak and no amount of financial support would have yielded positive results. Lagging public interest can be attributed, in turn, to two possible factors. Mexican elites and the emerging middle class were culturally disinclined, some historians have argued, to pursue technical and mechanical professions. Alternatively, all knew that even well-trained technicians and engineers faced few job prospects. Field positions with modern sector firms (in manufacturing, mining, construction, and public works) were largely monopolized by foreigners. Whether this was because hiring firms were prejudiced against Mexicans, or because

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[41] Kelley, "Education and Training."
[42] On weak state capacity and support, see Zuleta, "Fomento de la agricultura." For further discussion of the difficulties Mexican technicians encountered in finding work, see Cárdenas Garcia, Empresas, ch. IV.

it was cheaper to obtain trained foreigners rather than train Mexicans, the result was the same. Only after the revolution did Mexican technicians begin to gain ground, for instance, in mining and metallurgical centers.[43]

Whatever the combination of factors, technical education in Porfirian Mexico did not provide a "knowledge base" sufficient for a large number of local technicians to effectively engage the contemporary wave of new technology imports. Nor did it provide Mexican technicians with a firm basis for *learning* from new technologies. Certainly there were individual Mexicans who had the education, inclination, and experience to understand and engage new technologies on the global frontier, and thus to learn from them. But these were, for the most part, isolated individuals. Most graduates from Mexico's technical schools took jobs in government or the schools themselves.[44] There was no critical mass, especially working "in the field." They constituted small numbers, relatively isolated from the productive economy. Not one individual or society emerged to found a major program of basic or applied research within a university, private laboratory, or government office. Formal technical education did not produce a national technological community.

C. Opportunities for Interaction

Absent a knowledge base sufficient to close or even bridge the gap between local capabilities and the know-how embodied in imported technologies, learning can only come from direct interaction between technology and local actors. With relatively low levels of human capital, learning through interactions becomes more difficult, but more important. We can examine the possibilities for learning-by-using, -by-seeing, and –by-repairing in each of our

[43] Cárdenas Garcia, Empresas, ch. IV.
[44] The career of Antonio del Castillo, for instance, was typical: exceptional in its prominance, but not in his career path. See the Bulletin of the Geological Society of America, 1896, vol. 7, pp. 486-487.

three cases studies as well as with other newly introduced technologies. In each case, opportunities for interaction were constrained, and only rarely and exceptionally allowed for significant local learning and the local assimilation of imported know-how.

Sewing machines and a wide range of other small scale, multi-purpose technologies diffused widely and were used intensively. Widespread diffusion and intensive use supported extensive learning of how to use and work the machine. In sewing, this involved the simple mechanics of treadle motion and its translation to needle movements; the threading of bobbins and needles; the manipulation of cloth and thread; and, depending on the machine model, adjustments in needle, switches, and thread for different stitches and cloth types. For home purchasers, learning to use a machine often began with the salesman himself, in the store or more likely in the home.[45] Salesmen from Singer and other companies gave start-up lessons in homes and stores, and provided some consulting and trouble-shooting services in repeat visits. In urban areas, consumers could consult with salesmen in the store. In sweatshops and new clothing factories that installed large numbers of machines, in-house foremen or managers or contracted sales representatives trained new hires.[46] Sustained use in the home and workshop carried with it another layer of learning-by-using. Women and men became accustomed to mechanized sewing and the divergence in productivity between hand and machine methods. The sewing machine, perhaps more than any other single technology, lay at the vanguard of a broader social acceptance of mechanization.[47]

For those women and men who worked the machines in home or shop, hours of use and the inevitable occurance of jammed workings, rusted or broken parts, also carried with it a

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[45] See, for instance, Paterson to Singer Company, June 9, 1879 and Boker to Singer Company, February 7, 1882, SMCR box 103, folder 5; US General Consul Andrew Barlow, in U.S., Commercial Relations, 1896-97, p. 472; also González, San José de Gracia, p. 99.
[46] Porter, Working Women, p. 4.
[47] Cowan, "Women and Technology," among others.

certain amount of ad hoc trouble-shooting and tinkering. Some users proved adept at taking apart and greasing or jury-rigging the workings in response to problems. This ability had limits, however, especially among users isolated from a broader, machine culture (a large share of sewing machines imports went to rural users in isolated hamlets and villages).[48] In urban areas, the diffusion of sewing machines and other household-scale appliances supported the appearance of new neighborhood machine repair shops. Although these would become a fixture of urban and small town economic life in twentieth century Mexico, they remained, for the most part, essentially artisanal in nature. With sewing machines and many other small scale technologies, the effects of learning-by-using were limited to just that: the daily use of the machine and limited tinkering and repair. Using did not imply assimilating a deeper knowledge of its workings or the mastery of the ability to repair, modify, or replicate the thing, which remained largely a black box. Interactions were broad but not deep; technological learning was limited.

In contrast to sewing machines and other small scale product technologies, factory scale machines and systems—like the Owens automatic glass bottle blowing machine—were typically adopted and used by just one firm, or a small handful. This was the case for most new large-scale manufacturing technologies, including glass bottles, beer, cigarettes, cement, steel, and other consumer and producer good factories. Two factors limited diffusion and thus the scope of opportunities for interaction. First, the productive capacity of the new systems meant that the domestic market could support only a few. Rarely, however, did the size of the market fall below the output of one installation. Monopoly positions and overcapacity were not structurally determined.[49] Second (and relatedly), firms frequently sought ways to limit competition. The

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[48] The diffusion of sewing machines to rural households was substantial, and although the evidence is largely anecdotal, it is also substantial; see the longer discussion in chapter 4 of this project.

[49] There is some debate whether the Mexican market was sufficiently small as to doom new production systems to under-capacity and thus inefficiency (Haber, Industry) or whether the market could support scale operation of one or

most effective strategies included patent rights and special government concessions. Both factors shaped the Owens experience: investors' concern regarding profitability in a relatively small market pushed them to maximize the value of their patent rights through direct manufacture rather than through licensing the use-rights. No potential new user believed that royalty payments and profitablity were compatible.[50] As a consequence, only one firm acquired and used automated glass bottle machinery in Mexico. In most other new factory scale industries, diffusion beyond one firm was limited. Moreover, limited diffusion consequently constrained opportunities to interact with the new technology. Only one (or a few) firms, only a small handful of managers, engineers, technicians, and skilled workers had the opportunity to work directly with the new machines, and in nearly every case, these were typically foreign technicians and workers, at least through the first generation.[51]

The Vidriera Monterrey constituted an exceptional case of local learning. Although the "mexicanization" of the Vidriera and the local development of firm-level capabilities sufficient to produce one of the most technologically creative firms in twentieth century Mexico lies outside of the scope of this study, we can see the roots of later success in this early period. In glass as with sewing machines, the gap between the newly introduced technology and previous practice was too great to provide easy opportunities for local bridging through learning-by-using or –by-seeing. In both cases, the local level of human capital was insufficient to allow an initial assimilation of the know-how and skills embodied in the new machinery. In both cases, new

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more new systems, and under-capacity production owed to other factors (Gómez-Galvarriato, "Revolution;" Beatty, Bottles). For some consumer goods industries like beer and cigarettes, the domestic Mexican market could support at least a handful of firms. Their aggressive use of branding and marketing strategies, including trademarks, is evidence of the substantial level of competition between firms. This was also true for some producer goods industries (like cement) where low cost, high bulk goods meant that transportation costs were large and consumption was limited to regional markets.

[50] Beatty, "Bottles for Beer."

[51] Further research on technical positions in Mexico's new manufacturing centers is needed.

users relied completely on the expertise of foreign technicians to install, trouble-shoot, and teach (for sewing machine use) or directly operate (for the Owens machine) the new technologies.

With glass bottles, however, learning began with the efforts of Mexico's beer brewers to find a solution to the bottle supply problem that increasingly vexed their industry worldwide. All of Mexico's major brewers heard about the development of the automated Owens machine shortly after its introduction by the Toledo Glass Company in 1903, and all sought to acquire the new technology. For Juan Brittingham, traveling to the St. Louis International Exhibition provided an introduction to the machine, as well as the inspiration necessary to promote its acquisition over the hesitations of his potential partners. But international travel and direct observation were not necessary, as news of the invention quickly circulated among Mexico's brewers via their brewing networks in St. Louis and beyond.[52]

When Brittingham's investment group acquired the Owens rights, their technical knowledge extended only to the the productive potential of the machine and little more. Once acquired, further learning came in fits and starts, but acquired real momentum only when they decided to commercialize the technology themselves. Successful commercialization took several years because the new context—Mexico's undeveloped markets for raw materials, fuel, and skilled labor—as well as the new technology itself—had to be mutually adapted. These adaptions entailed an extensive process of exploration, feasibility studies, information gathering, dead-ends, trouble-shooting, and negotiating.[53] Over nearly a decade, all this yielded substantial learning. By the time the first bottles rolled off the factory belts in 1912, the Vidriera's investors were intimately familiar with the the technical requisits of glass bottle making, the demands of

[52] See the extensive correspondence between Juan Brittinham, Juan Terrazas, and Isaac Garza through the Spring and Summer of 1905 in the Brittingham archive; e.g. AHJB 20-0096, 02-0518, 0519, 0221 and 0222. Also Barrera Pagés, "Industrialización;" Romero Gil, "Las bebidas;" and Vizcaya Canales, Orígenes, pp. 76-77.
[53] See the extensive correspondence between Brittingham and Garza in Beatty, "Bottles for Beer," pp. 338-346.

their new technological system, and the nature of the Mexican context for production. The extensive challenges of this experience taught them that continued success would be more likely if they effectively internalized innovational capabilities. Negotiating the necessary adaptations delayed commercialization, but provided multiple opportunities for extensive local learning.

If small scale machine diffused widely but typically remained closed to deeper interaction, and large scale production technologies did not diffuse but potentially offered significant learning opportunities, the cyanide experience presents a third pattern. Once introduced and adapted to Mexican conditions, the cyanide process diffused quickly.[54] Technical information on the cyanide process was easy to obtain. The sustained work of experimentation and adaptation generated plentiful opportunities for learning. However, virtually all technical positions in the industry (both mining and metallurgical) were held by foreigners. Although Mexico had a proud tradition of formal education in mining engineering, and although many Mexican *ingenieros* worked in the country's mines and mills well into the 1890s, by 1900 or so there were very few who still held significant positions in the mining sector, and virtually none in the two or three dozen most important companies and districts. Thus Mexican engineers and technicians had virtually no interaction with the introduction and operation of the cyanide process. As late as 1926, well over two thirds of all mining engineers listed in that year's *Directorio de Minas* were foreigners; if we increase the sample to all technical and management positions, the proportion rises to roughly four fifths. Nearly all Mexican technicians in the sample worked for smaller, locally owned firms that did not adopt cyaniding.[55]

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[54] I develop a periodization of cyanide diffusion with early introduction and isolated, small-scale experimentation from 1893 to 1903, followed by heavy investments, rapid diffusion and large-scale plants from 1904-1908. The turning point came when the process was successful adapted to silver ores and complementary technologies (notably electricity) were in place and accessible. See chapter 6 of the project for an extended discussion.

[55] Southworth, Directorio de Minas.

D. Technical Networks and Communities

Industry-specific or national communities of technicians (or scientists, or engineers) can play a major role in promoting the acquisition and assimilation of new knowledge and engagement with imported technologies. Mexico witnessed the appearance and growth of numerous scientific and technical societies through the nineteenth century, forming the basis for a national community and network to promote, absorb, and diffuse new technological knowledge.[56] Along with the expansion of these organizations came the appearance of new industry-specific technical journals. In mining they included El Minero Mexicano and the Mexican Mining Journal. El Minero was published in Mexico City as the "*organo de las camaras mineras de la República*," a weekly paper "*dedicado al adelanto de la mineria, metalurgia, industria y comercio de la República Mexicana*."[57] Through the 1870s and 1880s it ran a number of articles and reports on mining processes involving cyanide, including, for instance, the use of potassium cyanide in reclaiming mercury from the patio process and its use in working with copper.[58] However, while the paper published extensive articles and reports on Mexican mining activities, these never contained the level of detailed accounts of metallurgical processes and techniques as could be found in the Mining and Scientific Press and the Engineering and Mining Journal.[59] It did not, in other words, provide a forum field engineers to report their results, interrogate those of others, and in so doing to build a network among field engineers also linked to laboratory technicians. As late as 1903 the paper had published only a few second-hand accounts of the cyanide process—first introduced in Mexico nearly a decade

[56] These included particularly societies focused on Mexican geography, geology, and other natural sciences, including, for instance, the Instituto Nacional Geológico, the Sociedad Mexicana de Minería, and others.
[57] The other mining papers in Mexico were published in English.
[58] El Minero Mexicano, December 10, 1874, September 22, 1887, February 6, 1890.
[59] For several examples, see descriptions of cyaniding plants in El Minero Mexicano, February 1 (p. 52), 15 (p. 74), and 22 (p. 88), 1900.

before—taken from (for instance) the Boletín de Agricultura of El Salvador![60] Mexican mining engineers played only a very small role in the dissemination (or interpretation) of cyaniding *know-how* to a Mexican audience. They kept closely abreast of scientific developments in Europe and the United States and were quick to report on these in the classroom and the Mexican scientific press. However, the vast majority of scientific publications in late nineteenth century Mexico were just this: informed reports and summaries of recent advances abroad. These represented the importation of new knowledge, but not its effective assimilation and application by more than a small number of individuals who had little direct contact with productive activities.[61]

This proved crucial in mining because the adaptation of the cyanide process to Mexico's silver ores crucially depended on technical networks through which mining and metallurgical engineers could share information. Without these networks, local adaptation and diffusion of the cyanide process would not have happened.[62] These networks were forged in the mining schools of the United States, England, and Germany that produced a new generation of "scientific" miners beginning in the 1890s.[63] The application of science to mining and refining problems, the professionalization of engineering, and rapid technological change on both micro- and macro-levels came together to transform the industry and effectively drive out old school miners. This was true in the United States (and Australia and South Africa and India, for instance) as it was true in Mexico. "They are not miners but chemists," wrote the editor of The Mexican Mining Journal in 1908; "The business of mining does not consist simply of taking ore out of the ground.

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[60] El Minero Mexicano, January 8, 1903, pp. 15-17, January 15, 1903, pp. 27-29, and January 22, 1903, pp. 38-40.
[61] See, for instance, the report of Ingeniero Carlos F. de Landero on the chlorization of silver; and Landero, Exámen termoquímico.
[62] This is detailed in chapter 6 of the book.
[63] On this transition in the western United States, see Ochs, "Mining Engineers;" Hovis and Mouat, "Miners;" Burt, "Innovation;" and Spude, "Cyanide."

It is much more complex and difficult and involves the science of chemistry and mechanics and delicate problems of engineering such as were not necessary in the early days of the western United States or of Mexico."[64] But in contrast to young engineers from the United States, Mexican technicians and engineers were unable to break into the networks that dominated mining communities throughout North America. Mexico was no different than other countries and was part of an international trend; even British engineers in the early twentieth century failed to keep up with those from the United States, Germany, and (increasingly) Japan.[65]

There were, of course, individuals in Mexico with the education, inclination, and experience to fully engage imported technology, assimilate foreign know-how, and push forward projects of technological innovation. These individuals, however, did not in the aggregate constitute the critical mass of an effective Mexican technological community. Five issues were critical. First, the numbers were small, as we have seen.[66] Second, the verticle links between this small but capable elite and other social groups (a somewhat broader group of non-formally trained technicians, skilled workers, and the literate public) were weak. There were, for instance, few programs to funnel promising younger students into technical and engineering programs in the way that apprenticeships had done for high-level artisanal work a half century and more before. Third, the linkages between a small scientific and technical elite and the hands-on, applied work of productive activity in factories, mines, and elsewhere were also weak. As we have noted, some have attributed this to a cultural disinclination for applied mechanics, as opposed to more theoretical, academic, or policy paths. Other explanations are also possible, however, especially the preference for foreign trained technicians. Low demand yielded few

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64 The Mexican Mining Journal, January, 1908, p. 10.

65 Lazonick, Favorites, pp. 283-284.

66 In the 1970s UNESCO placed the number of engineers per capita necessary to sustain development at 9 per every thousand people (Strassman, Technological Change, p. 275). This would have implied well over 10,000 in 1910 Mexico, rather than the roughly 450 produced by the engineering schools over 35 years.

entrants which weakened educational programs and reinforced the preference for foreigners. Fourth, networks for information gathering were exceptional rather than typical, and access to crucial international networks could prove limited. What set the Owens experience apart was an exceptional access to cross-border networks through Juan Brittingham, who operated as a key information broker in this enterprise and many others. He was not alone, and immigrant entrepreneurs frequently played this role in Mexico and elsewhere, but there were few other effective nodes for information exchange of the kind that underwrote effective learning and technological capacity-building in the Owens/Vidriera case, or among US engineers in the cyanide case. Finally (and given these factors), entrepreneurs and investors (both Mexican and foreign) found it relatively easy to hire foreign technicians and engineers to install, adapt, and operate new technologies. Proximity to the US skilled labor market played a role here, and Mexico benefited (as least in the short term) from the spillover of US engineering talent. However, as most opportunities for interaction fell to this group, and most technological learning soon left the country, Mexico lost opportunities for technology imports to stimulate local learning and enhance domestic technological capabilities.[67]

E. Government Policy

There is substantial evidence that the Porfirian government understood the importance of generating a domestic capacity to engage the global technological frontier, and thereby to work towards a degree of technological independence from imported technologies and foreign expertise. Government officials on a number of occasions discussed, debated, and sometimes enacted a range of activities, policies, and procedures that aimed to support local learning and

[67] The conventional "foreign" versus "Mexican" dichotomy is not entirely useful here. What matters is the distinction between long term versus short term workers, and their relative degree of interaction and integration with local activities and interests.

technological capacities. As we have briefly noted, government mininstries and agencies (principally Fomento) sponsored the publication of gazettes and pamphlets in order to diffuse new scientific and technical knowledge within Mexico.[68] The Ministry also sponsored a wide range of technical exhibitions in Mexico City and regional centers. These were designed to display new technologies—most developed abroad—and at the same time to host agents of foreign distributors and manufacturers. These exhibitions, however, served more to support local adoptions and the import trade rather than local assimilation of new knowledge.[69]

Government policy also sought to support education and training beyond formal education. In many of its contracts and concessions with new businesses, often foreign, the government often contained clauses stipulating that students in Mexican technical schools be taken on, in a learning capacity, for a period of several months.[70] Similar proposals to enhance local learning were raised in congressional debates but were never enacted into law. Most importantly, these included the major patent law reform project of the late 1880s, which initially proposed to limit foreigners' rights to their inventions in Mexico and sought to require local use and local manufacture in return for patent protection.[71] The intitial proposal essentially aimed to prevent foreign patentees from acquiring sales monopolies in Mexico by requiring local use and manufacture, and by allowing Mexicans to patent foreign advances. As late as 1893 Congress asked Fomento to adopt "effecive procedures to favor the construction and exploitation of apparatuses and products of notorious utility in the country," believing that local manufacture would enhance local capacities.[72] But none of these objectives were enacted into law. The new

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[68] Among others, see Landero, Exámen termoquímico.
[69] Although the potential of simple displays of machinery at industrial exhibitions to support "learning-by-seeing" should not be underestimated. Industrial espionage is based on just this.
[70] Beatty, Institutions, chapter 6 on Industrias Nuevas contracts; on the terms of extraction concessions, see Engineering and Mining Journal, December 31, 1910, p. 1312; also Cárdenas García, Empresas, p. 66
[71] See Beatty, Institutions, chapter 4 for a full discussion of these issues.
[72] Sánchez Flores, Tecnología, p. 382.

1890 law ended the possibility of "patents of introduction," which previously enabled Mexicans to acquire protection for new imported technologies if they were the first to put them into practice in Mexico. Nor did the government move to make the know-how embedded in patent applications and specifications easily available to the public. Although all were presumably available for examination in the Fomento offices, and brief, three- or four-line notices were published in the *Diario Oficial*, not until 1903 were the full specifications published, and there remained no regional access to information in this highly centralized system.[73]

Government policy worked aggressively to promote the investment in new technologies. It did not, however, work to promote the transfer of technological capabilities to Mexican firms and Mexican engineers, technicians, and workers. Could Mexico have adapted to this transformation and effectively trained Mexican nationals to play a role in the new environment? What the Díaz government did not do was as important as what it did. Other governments at the same time worked more aggressively to promote domestic technological capacity. From supporting young men's studies in foreign universities and workplaces to the creation of regional mining inspectors: formally trained, appointed by the federal government, charged with surveying conditions, keeping abreast of international developments, visiting mines, sharing information, advising on best practice.[74] Mexico did fund foreign travel and study for a small number of young men dedicated to technical careers.[75] Like the graduates of Mexico's technical schools, however, these often found employment back home scarce. The paradigmatic case is of

[73] Compare, for instance, easy regional access to British patent specifications; in just a few years in the 1850s, for instance, tens of thousands of visits were made to one regional patent office library; Inkster, "Patents."

[74] Jack, "Introduction," 84, pp. 20-21, though we should note that in New Zealand, these mining inspectors were likely to be skeptical early on about the cyanide process and often served to slow its adoption and diffusion instead of facilitating technological change.

[75] Bazant, "La enseñanza," pp. 186-196. See also El Minero Mexicano, September 22, 1887, p. 299, on the young Mexican Luis Lajous, a graduate of the Escuela Central de Artes y Manufacturas in Paris and the Escuela de Ingenieros, in Mexico, identified as "the first and only industrial scientist in Mexico, until now, whose deep knowledge promises a happy future." Fomento subsequently funded two further years of practical study in US industrial centers.

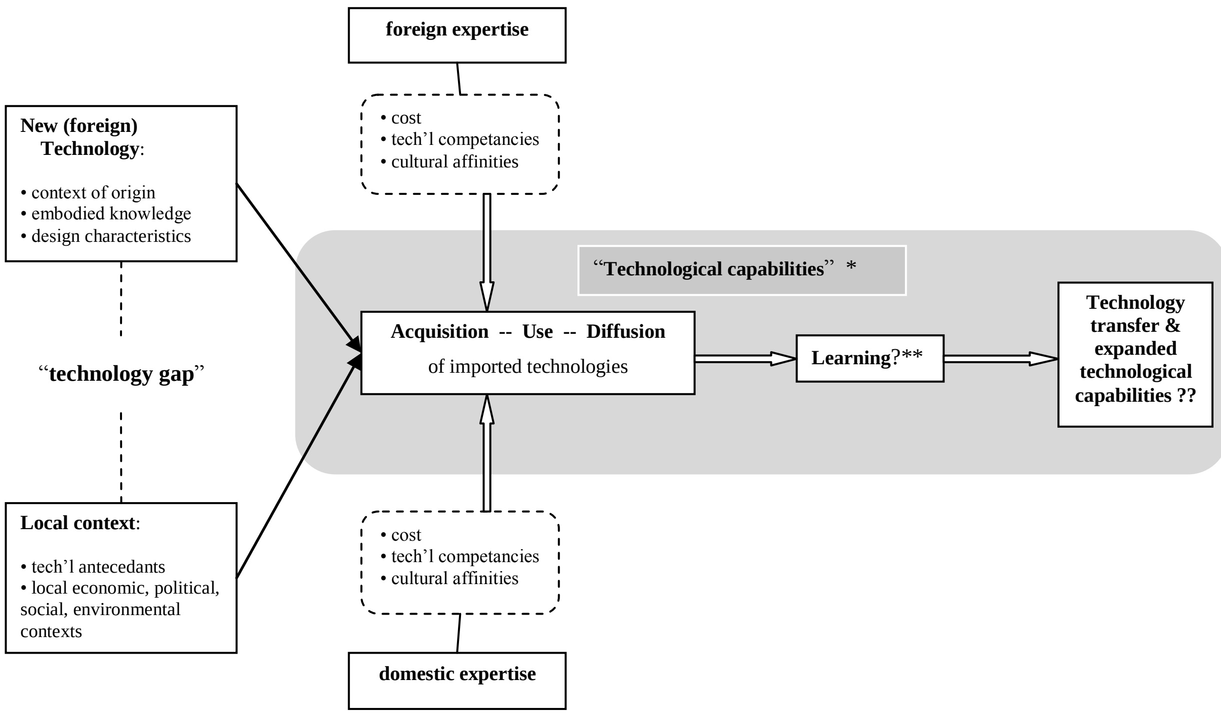
course Japan, but others also adopted policies and extensive programs to increase the training and exposure and opportunities for local technicians and engineers.

In the end, government policies to promote local learning and a level of local technological independence and creativity were few and ineffective. This was partly due to weak state capacities—both fiscal and administrative—but also due to lack of vision. Although by 1900 Porfirian officials were increasingly concerned about the unbalanced weight of US investments and interests, and worked in both petroleum and railroads to address this issue, and although there was substantial rhetoric about the dangers of falling "tributary" to the US economy, there was little explicit concern expressed about an ongoing dependence on foreign expertise.

Conclusions

The adoption of new technologies has long been seen as the most effective way for relatively poor countries to achieve the wealth and welfare levels of global leaders. In late nineteenth century Mexico, intellectuals and investors repeatedly articulated this vision, and sanguine views about the transformative power of the "most modern" machinery pervaded most levels of Mexican society, far outweighing suspicion and resistance. But technology imports did not impoly learning and effective technology transfer. What factors shape the ability of nations to turn technology imports into a capacity for sustained innovation and technological creativity? Multiple paths competed in nineteenth century Mexico and the story was neither unilinear or deterministic. Outcomes diverged from the goals of those who promoted the importation of new techniques; Mexico did not import and innovate all that was available abroad; technological change came slowly and incrementally, frequently fraught with difficulties. New projects produced a litany of complaints about obstacles to the installation, operation, repair, and adaptability of imported machines, parts, tools, and processes. All were highly contingent on the intimate relationship between technology and contextual environment. This relationship conditioned the long term consequences: sometimes by displacing domestic creativity and deepening technological dependency, sometimes by creating a modern sector relatively isolated from domestic society, and sometimes by stimulating local capabilities. The patterns established during this early modernizing transition critically shaped competing development paths for Mexico’s twentieth century.

FIGURE 1:


foreign expertise
• cost
• tech'l competancies
• cultural affinities
New (foreign) Technology:
• context of origin
• embodied knowledge
• design characteristics
"technology gap"
Local context:
• tech'l antecedants
• local economic, political, social, environmental contexts
"Technological capabilities" *
Acquisition -- Use -- Diffusion
of imported technologies
Learning?**
Technology transfer & expanded technological capabilities ??
• cost
• tech'l competancies
• cultural affinities
domestic expertise

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