

Codification, Technology Absorption, and the Globalization of the Industrial Revolution*

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Abstract

This paper examines the global adoption of technology in the late nineteenth century. We construct several novel datasets to test the idea that the codification of technical knowledge in the vernacular was necessary for countries to absorb the technologies of the First Industrial Revolution. We find that comparative advantage shifted to industries that could benefit from these technologies in countries and colonies with access to codified technical knowledge, but not in other regions. Using the rapid and unprecedented codification of technical knowledge in Meiji Japan as a natural experiment, we show that this pattern emerged only after the Japanese government codified vast amounts of technical knowledge. Our findings shed new light on the frictions associated with technological diffusion and offer a novel explanation for why Meiji Japan was unique among non-Western countries in successfully industrializing during the first wave of globalization.

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“At present, the learning of China and Japan is not sufficient; it must be supplemented and made complete by inclusion of the learning of the entire world... I would like to see all persons in the realm thoroughly familiar with the enemy’s conditions, *something that can best be achieved by allowing them to read barbarian books as they read their own language*. There is no better way to enable them to do this than by publishing [a] dictionary.”

Sakuma Shozan,¹ 1858, quoted in [Hirakawa \(2007, p. 442, emphasis added\)](#).

1 Introduction

Although recent econometric evidence finds that modern economic growth started in England around 1600 ([Bouscasse et al., 2023](#)), the spread of economic development has been highly uneven. For example, there are currently only four types of high-income countries in the world: English-speaking countries, countries close to England, resource-abundant countries, and Japan and its former colonies.² While economists have made enormous progress in understanding why English-speaking countries, Europe, and Petrostates are rich, data-driven studies of why the First Industrial Revolution (henceforth “Industrial Revolution” or IR) first spread to Japan and not to any other non-Western country are almost nonexistent. After centuries of resisting economic and social change, Japan transformed from a relatively poor, predominantly agricultural economy specialized in the exports of unprocessed, primary products to an economy specialized in the export of manufactures *in under fifteen years*.³ Why did Japan in the Meiji Period (1868-1912) succeed in this structural transformation while so many other countries failed to develop in this period?

We bring several novel datasets to bear on this question and test one of the main theories proposed by [Mokyr \(2011\)](#): namely, that an essential component of the Industrial Revolution was the development of what [Stevens \(1995\)](#) calls “technical literacy,” i.e., the *codification* of engineering, commercial, and industrial practices. We call this knowledge “technical knowledge.” We hypothesize that codification reduces technology access costs by enabling entrepreneurs to read about technology in their own vernacular. While there is extensive evidence that what [Mokyr \(2016\)](#) refers to as the culture of Enlightenment created vast amounts of codified technical knowledge in Western European languages, our understanding of codification beyond Europe is much more limited. For example, we have no idea how many books containing technical knowledge a literate person in China could have read in 1870 or the extent to which the number of books containing codified knowledge changed over time. As a result, prior work has been unable to explore how access to technical knowledge in the vernacular contributed to the *spread* of the Industrial Revolution.

An ideal experiment would require both cross-sectional and time-series variation in technical knowledge supply. Cross-sectional variation allows us to examine whether industries that stood to gain the most from the supply of codified knowledge grew faster in countries that supplied this knowledge. Time-series variation lets us explore whether the timing of this faster growth coincides

¹We follow the convention of referring to Japanese, Korean, and Chinese historical figures using their surname first, followed by their given name.

²We define high-income countries as those with a purchasing-power-parity adjusted GDP per capita of 50 percent or more than the US level in 2022, as measured by the World Bank. See Appendix [H.1](#) for more details.

³We also see this sudden transformation in the efficiency of modern industry. For example, [Clark \(1987\)](#) finds that Japan transitioned from having no modern textile and weaving mills in 1870 to having modern mills that achieved levels of output per unit of capital that were 96 and 98 percent of those in Britain by 1910. By contrast, the Chinese textile and weaving industries had 79 and 66 percent output efficiency relative to Britain’s in 1910.

with the provision of this knowledge. The experiences of Meiji Japan and the other codifiers of knowledge in the late nineteenth century provide precisely this empirical setting.

We test the link between codified knowledge and productivity growth in Meiji Japan and the late 19th-century global economy by constructing the first dataset that enables us to quantify the extent of codification by language, the usefulness of this codification by industry, and industry-level export and productivity growth in 37 “regions” (some of which are countries) in the late nineteenth and early twentieth centuries. We build this dataset by scraping the catalogs of libraries for every major language, digitizing technical books for every major tradable industry, digitizing the synopses of British patents issued between 1780 and 1852, digitizing bilateral industry-level trade data for Japan and the U.S., merging these trade data with extant trade datasets to create the first multicountry, bilateral, industry-level, trade dataset for the nineteenth century.

We establish three novel stylized facts about the global spread of the Industrial Revolution and the uniqueness of Japan’s nineteenth-century industrialization, “the Meiji Miracle.” The first stylized fact is that Meiji industrialization was exceptional in comparison to other regions in the periphery. We find that late 19th-century Japan experienced a surge in the share of manufacturing exports, surpassing that of any other region in our sample. Notably, this surge in manufacturing exports happened rapidly and much later than well-known events in nineteenth-century Japanese economic history. In particular, twenty-five years after Japan had jumped to free trade (1858) and fifteen years after the Meiji Restoration (1868), eighty percent of Japanese exports were still primary products. Similarly, average annual real per capita GDP growth between 1870 and 1883 was only 0.6 percent. In other words, there is no evidence that Japan’s natural comparative advantage or state reforms were gradually shifting export patterns in the manufacturing sector. However, in a brief 13-year period from 1883 to 1896, Japan’s manufacturing export share tripled and then remained at around 60 percent of total exports until the Second World War. Thus, the puzzle of Japan’s development is why Japanese manufacturing exports grew so suddenly, and so much. It was as if Japanese entrepreneurs had suddenly learned how to do modern manufacturing.

The second stylized fact is that in 1870, entrepreneurs in most regions—including Japan—had almost no technical books to read in their vernacular languages. We document this by scraping thousands of libraries containing books in 33 major languages and find that in 1870, 84 percent of all *technical* books were written in just four languages: English, French, German, and Italian. People who could not read these four languages were therefore technically illiterate. For example, a person who could only read Arabic would have been able to read only 71 technical books in 1870. Libraries for other major non-European languages, such as Chinese, Hindi, and Turkish, have extensive collections of books but contain similarly small numbers of technical books. By contrast, speakers of major European languages would have had access to thousands of technical books. This puts the achievements of the Enlightenment, with its emphasis on the “coding, storing and transmission of technical knowledge” (Berg, 2007, p. 125) in comparative perspective for the first time. In short, outside of the languages of the Enlightenment, literacy in the vernacular was a ticket to reading the humanities and history, not science.

The third stylized fact is that the Japanese language is unique in that it started at a low base of codified knowledge in 1870 but experienced explosive growth in the publication of technical books, catching up with the West in the middle of the 1880s. By 1890, there were more technical books in Japanese than in any other language except English and French. This catch-up in codification coincides with Japan’s sudden industrialization. Japan suddenly began exporting manufactured products shortly after Japanese entrepreneurs could read *in Japanese* how to make these products.

How did Japan achieve such remarkable growth in the supply of technical books? We show that the Japanese government was instrumental in overcoming a complex public goods problem,

which enabled Japanese speakers to achieve technical literacy in the 1880s. We document that Japanese publishers, translators, and entrepreneurs initially could not translate Western scientific works because the Japanese language lacked the words needed to describe the technologies of the IR. The Japanese government solved this coordination problem by creating a large dictionary that contained Japanese jargon for many technical words. Indeed, we find that new word coinage in the Japanese language grew suddenly after a massive government effort to subsidize translations produced technical dictionaries and, subsequently, a large number of translations of technical books.

Beyond producing technical dictionaries, the Meiji government also made substantial investments in codifying knowledge by paying for the large-scale translation of technical knowledge from the West (Montgomery, 2000). Our analysis of the institutional affiliations of these translators reveals that 74 percent of them were government employees, indicating the relative importance of the government in funding this public good. This created two sub-periods in Meiji Japan: a period before the 1880s, in which Japan had completed substantial economic reforms but had codified less than half as much as had been codified in Spanish (and a small fraction of what had been codified in French, English, Italian, and German), and a period afterward in which Japanese people could read Western technical knowledge at a level equal to or exceeding that in the West.

Together, our stylized facts show that the sudden increase in codified knowledge and the sudden surge in manufacturing specialization, which occurred shortly thereafter, were unique to Japan in the 19th century. Thus, Japanese manufacturing export growth rates didn't gradually increase as institutions improved; rather, a rapid increase in manufacturing occurred only after Japan codified approximately the same amount of knowledge as Germany had in 1870. Together, we interpret these three stylized facts as suggestive evidence that access to technical knowledge may have been a necessary (although not sufficient) condition for the spread of the IR.

In the second part of the paper, we exploit the natural experiment of Japan's rapid codification of knowledge to test this hypothesis rigorously. This requires both time series variation and cross-sectional variation in technical knowledge; thus, we move our empirical analysis to the industry level. In particular, we develop a method to quantify the supply of useful, codified knowledge generated by the IR for each industry. We use a text-based approach that closely follows how codified technical knowledge was disseminated in this period: through the publication of technical manuals. For example, "The American Cotton Spinner, and Managers' and Carders' Guide," published in 1851, contains a description of every aspect of operating a cotton spinning mill from the dimensions of the building, to setting up the gearing which distributes power through the building, as well as the operation, and maintenance of each machine used in production.

For each industry, we calculate the similarity of text from these historical technical manuals (in English) to the text of British patents using cosine similarity, the standard metric in natural language processing. We call this measure "British Patent Relevance" or BPR. Our BPR measure rises in the similarity of the word use in an industry's technical manuals to that in British patents. Thus, it serves as a metric for assessing the usefulness of the knowledge codified in British patents for a particular industry. Reassuringly, industries such as textiles, which benefited the most from the new technologies of the IR, have descriptions of production processes, including flagship technologies such as spinning machinery and steam engines, that also feature prominently in patent texts. As such, the contents of patent texts are relevant for manufacturing textiles. On the other hand, the cosine similarity between word use in manuals and patent descriptions is smaller for industries like charcoal, which suggests that the makers of charcoal benefitted little from IR technologies. Importantly, BPR is a measure of the *supply* of new technical knowledge; it does not use *any* (potentially endogenous) information on what was translated in Japan or elsewhere.

To measure outcomes at the industry level, we use our novel, bilateral, industry-level trade dataset to compute industry-level export growth from 1880 to 1910. In robustness checks, we also use productivity growth estimates based on [Costinot et al. \(2012\)](#) and [Amiti and Weinstein \(2018\)](#). These methods are well-suited to data-scarce environments such as ours.

Armed with these data, we examine the relationship between the supply of technical knowledge and export/productivity growth in Japan and around the world. We show that Japanese export and productivity growth was higher in the industries where the *supply* of technical knowledge produced by the IR was greater. The estimates point to a large effect of access to technical knowledge on growth. Our estimates imply that a Japanese industry with a one-standard-deviation higher British Patent Relevance measure experienced annual export and productivity growth rates that were 12 and 1.2 percentage points faster, respectively.

We use several features of our setting to make the case that this relationship is likely to be causal. First, we exploit the fact that Japan was unique among periphery countries in codifying knowledge. If our findings for Japan are causal, this would suggest that other periphery countries, which did *not* have access to codified knowledge, should not have a similar association between industry growth and BPR. Indeed, we find that, on average, other regions do not exhibit a similar effect. Interestingly, other low-income regions and Asian regions tend to exhibit a negative relationship with BPR, suggesting divergence, although this negative effect is not always statistically significant. In contrast, for regions speaking one of the other major codifying European languages (English, French, German, and Italian), we find a similar positive effect of BPR on growth, though one that is smaller in magnitude. In summary, in the cross-section of countries, we find supporting evidence that only codifying countries have industry growth patterns systematically related to BPR.

Second, we exploit the sharp timing of codification in Japan. In most settings, identifying the effect of codification on growth is challenging, as codification typically proceeds slowly, making it difficult to rule out confounding factors. However, our third stylized fact is that Japan can be separated into two relatively well-demarcated periods: one in which Japan resembled other technically illiterate periphery economies and one in which codification in Japanese is comparable to that in the most codified Western European languages. Consistent with our hypothesis, we find a positive and statistically significant effect of BPR on industry growth in Japan *only after* Japan became technically literate. Indeed, until 1890, Japan looked remarkably similar to the rest of the global periphery, and Asia in particular, in which comparative advantage shifted away from industries that heavily used British technology.

Taken together, our results lend support to the idea that low-cost access to technical knowledge, which at the time usually meant access *in the vernacular*, was a necessary condition for the diffusion of IR technologies and modern manufacturing growth more broadly. Moreover, our results suggest that for regions not strongly affected by Enlightenment efforts to reduce what [Mokyr \(2011\)](#) terms “access costs,” the codification of technical knowledge was a complex public good that required state provision. In the final section of the paper, we show that the Meiji model of technology policy had a lasting influence beyond Japan. In particular, we demonstrate that policymakers in postwar Korea and China, who had studied in Japan and were heavily influenced by the Meiji model of economic development, adopted similar codification policies.

2 Related Literature

This paper contributes to three strands of the literature. First, our results inform the technology adoption lags literature (e.g., [Griliches 1957](#); [Rosenberg 1972](#); [Hall 2004](#); [Comin and Hobijn 2010](#)). In particular, our finding that state-led codification lowered technology access costs in Meiji Japan helps us understand the strikingly large cross-country technology adoption lags documented in

Comin and Hobijn (2010) for the 19th century. Our results suggest that in the absence of similar state-led technology policies in other parts of the global periphery, the costs of technology adoption were too high. As such, the paper offers a new explanation for a longstanding puzzle in economic history: why IR technologies failed to take hold beyond a few technologically advanced countries during the long 19th century (Clark, 1987; Allen, 2011; DeLong, 2022). Our explanation builds on Mokyr (2011)’s pioneering work on the importance of “technical knowledge” for European industrialization, though with a Gerschenkronian (Gerschenkron, 1962) twist.⁴ In particular, for regions that were physically distant from Europe and linguistically distant from major European languages, the provision of technical knowledge required the state’s involvement due to its public good-like attributes. This points to a novel arena where the Gerschenkronian argument of the state as a critical agent in late industrialization may apply.

Second, our results inform our understanding of the sources of Japan’s unique industrialization. Previous work has examined the introduction of new institutions (Sussman and Yafeh, 2000), modern banking (Tang and Basco, 2023), railroads (Tang, 2014), subsidized firms (Morck and Nakamura, 2007, 2018) and trade (Bernhofen and Brown, 2004, 2005). This careful work has not found large positive impacts of these policies on economic outcomes and sometimes finds the policies were counterproductive. For example, Sussman and Yafeh (2000) conclude that “the great majority of the Meiji reforms—including the establishment of the Bank of Japan and the introduction of ‘modern’ monetary policy, the promulgation of the Meiji Constitution, and the introduction of parliamentary elections—produced no quantitatively significant market response.” In the end, they conclude that only land tax reform and Japan’s adoption of the gold standard mattered to investors.

Our findings offer a resolution to the puzzle of what drove the Meiji Miracle. Importantly, our result that BPR mattered for industry growth from the 1890s, but not before is consistent with the latest evidence suggesting that Japanese convergence to Britain in terms of GDP per capita only started in 1890 and was driven by productivity growth in manufacturing (Broadberry et al., 2025). Moreover, our findings also explain why cross-country technology adoption lags begun to decrease in Japan during the Meiji period (Comin and Hobijn, 2010).

These results are particularly helpful in placing the “Meiji Miracle” in a comparative perspective. That is, while the more standard modernization efforts of the Meiji government, such as the introduction of banking and railroads, certainly contributed to industrialization, given their fairly widespread adoption in other parts of the global periphery, which were characterized by more modest growth and longer cross-country technology adoption lags, it is unlikely they can give a full account. In contrast, our paper provides empirical support for the long-standing tradition in Japanese economic history that has emphasized the more distinctive aspects of the Japanese government’s efforts to adopt Western technology. In fact, our results suggest that the Japanese state may have been uniquely successful in relaxing key constraints to adopting Western technology.

Third, our paper is related to prior research that has explored the effects of knowledge codification. Previous work has examined the effects of new codification technologies (Dittmar, 2011), the development of written language (Brown, 2024), and ideological barriers to knowledge diffusion (Abramitzky and Sin, 2014). We contribute to this literature by showing what is, to the best of our knowledge, the first evidence supporting the hypothesis that codified knowledge in the vernacular reduces technology access costs and benefits industries most reliant on that knowledge. This helps explain why prior work has found developmental effects of knowledge codification on

⁴As such, our paper is related to recent studies that examine the role of Enlightenment ideals in Europe and their effect on industrialization (Squicciarini and Voigtländer, 2015; Almelhem et al., 2023). Our focus is on the spread of technology outside of Europe and the context of the Enlightenment.

more indirect measures of development such as city growth (Dittmar, 2011), education, and health outcomes (Brown, 2024).⁵

The remainder of the paper is structured as follows. Section 3 discusses why Japan adopted its technology policy and provides details on the historical context and what the Japanese government did. Section 4 discusses the data we use and how we measure codification and British Patent Relevance. Section 5 presents our main results. Section 6 conducts a number of robustness exercises; Section 7 considers the lasting impact of Meiji technology policy beyond Japan; and Section 8 concludes.

3 Japanese Industrialization and Technology Policy: Historical Context

Nineteenth-century Japan presents an interesting study of late industrialization. In a very broad sense, Japan in the 1870s was similar to other poor, predominantly agricultural areas of the global periphery that had missed out on the first wave of industrialization. The most recent estimates of GDP per capita and wages for Japan confirm that it was a low-growth, low-wage society diverging from northwestern Europe until at least the 1870s (Bassino et al., 2019; Kumon, 2022).⁶ In this section, we introduce and provide novel evidence for the main stylized facts that motivate our empirical analysis. We first examine Japan’s unique industrialization amongst economies in the periphery. Second, we discuss Japan’s technology policies and show how they contributed to Japan’s rapid and unprecedented codification of technical books in the periphery.

3.1 Japan’s shifting export composition

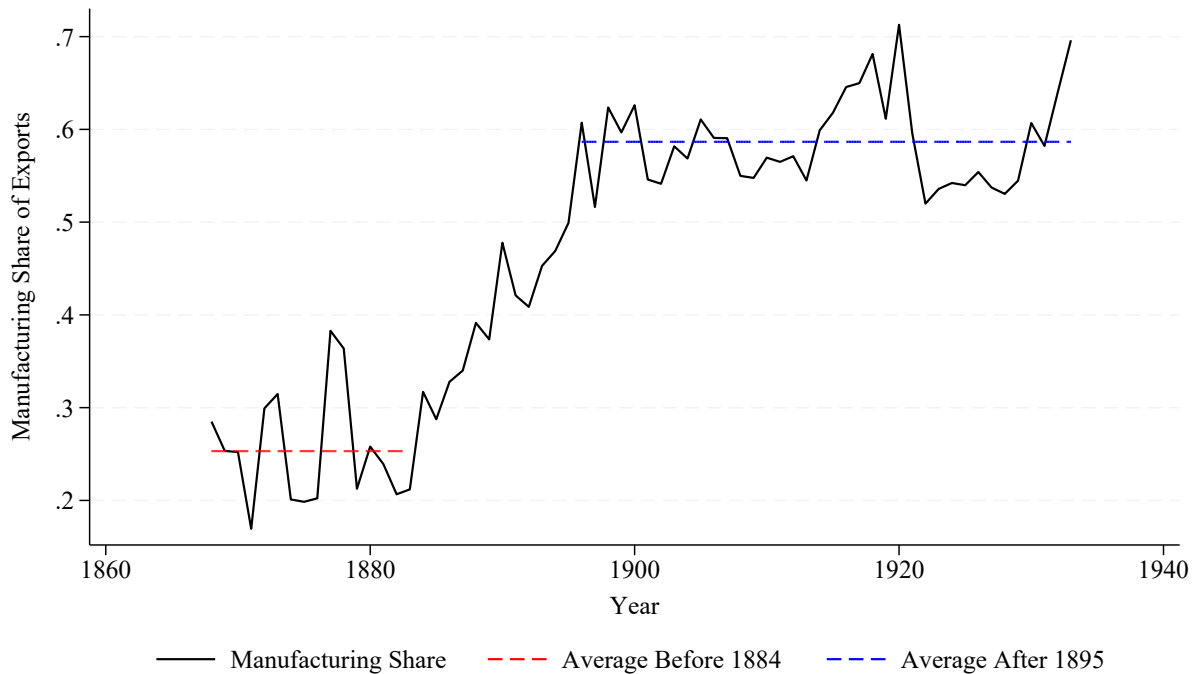
Starting in the closing decades of the nineteenth century, Japan began to industrialize (e.g., Yamamura 1997). The Maddison data suggest a growth acceleration with average annual per capita GDP growth rising from 0.6 percent between 1870 and 1885 to 1.4 percent between 1885 and 1900. Fukao et al. (2020) estimate that the average annual growth rates of TFP and labor productivity were even higher (between 1885 and 1899), coming in at 1.5 percent and 1.8 percent, respectively. They find that by 1913, Japanese TFP was 44 percent higher than it had been in 1885, and labor productivity was 64 percent higher. Japan was clearly escaping from the Malthusian equilibrium.

These aggregate changes obscure the rapid industrialization occurring in the small but rapidly growing manufacturing sectors. To understand the timing, speed, and scale of this change, Figure 1 plots the manufacturing share of exports in Japan during this period. Consistent with other evidence of a stagnating economy cited above, the trade data indicate that the economy was highly specialized in the exports of primary products until the early 1880s. Between 1868 and 1883, manufacturing exports as a share of total exports hovered around 25 percent with no discernible upward trend. The share suddenly began rising after 1883. Starting in 1884 and continuing through 1896, the share of Japanese manufacturing exports rose steadily before stabilizing at an average level that was more than double its earlier average for over forty years. Since this shift

⁵There is less work on how tacit knowledge affects development, with the exception of a recent paper by Bekkers et al. (2022) examining whether technological catch-up is slower in sectors that are more tacit-knowledge intensive.

⁶There is some debate about whether proto-industrialization was experienced in the late Tokugawa period. Building on Saito and Takashima (2016), Bassino et al. (2019) estimate annual GDP per capita growth of 0.26 percent for the period 1721-1874, driven by growth in the secondary and tertiary sectors. Based on these findings, the authors argue that Japan may have improved its relative position within Asia even before the Meiji Restoration in 1868. However, Kumon (2022) casts doubt on these findings, arguing that there is no direct evidence of growth in the secondary and tertiary sectors during this period.

Figure 1: Manufacturing Share of Exports (Japan)



Note: Data sourced from Oriental Economist (1935) *Foreign Trade of Japan: A Statistical Survey*. Tokyo: Toyo Keizai Shinposha.

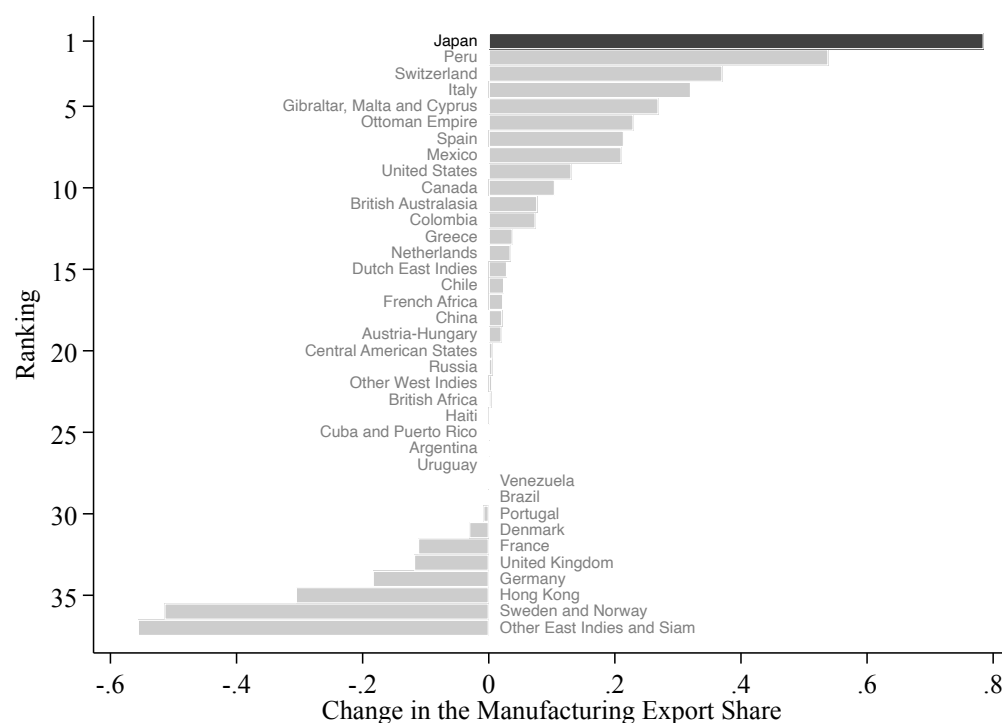
happened twenty-five years after Japan opened to trade, it is hard to explain the shift in terms of Japan simply having a comparative advantage in manufacturing.⁷ As a result, by the turn of the twentieth century, Japan was specialized in the export of manufactured products. Moreover, Figure 2 shows that no other economy displayed a similar change in its export composition, which raises the question of what happened in Japan and why it didn't happen elsewhere.

3.2 Meiji technology policy

We hypothesize that a state-led technology absorption effort, unique in scale, provided widespread access to the technical knowledge needed to adopt the technologies of the IR. After centuries of self-imposed isolation, the U.S. forcibly opened Japan to foreigners in 1854 and to trade with Western countries in 1858. The Tokugawa shogunate, which had ruled Japan since the 1600s, was overthrown in the 1868 “Meiji Restoration” and replaced by an oligarchy of rival nobility ruling in the name of Emperor Meiji. From its inception on April 5, 1868, the Meiji Government declared that the assimilation of Western knowledge would be a central tenet of its policy. The Charter Oath, Emperor Meiji’s five-sentence statement of the objectives of the fledgling government, stated that “knowledge shall be sought throughout the world so as to strengthen the foundations of imperial rule.” (Hirakawa, 2007, p. 338) Thus, all members of the new government were required

⁷Similarly, Japan’s Meiji reforms began in 1868 and many of the most important ones, like tax reform, foreign missions, peak hiring of foreigners, educational reform, postal reform, telegraph construction, banking reform, military reform, judicial reform, etc., were implemented by 1875, so it is not obvious why these reforms should have caused the manufacturing export share to stagnate only to sharply increase starting in the 1880s.

Figure 2: Change in the Manufacturing Share of Exports by Country (1880-1910)



Note: Percentage point change in the share of manufacturing exports relative to total exports of the country. For non-reporting countries, we use imports to reporting countries to estimate exports. We include the following SITC categories in manufacturing: code 6 (Manufactured goods classified chiefly by material), 7 (Machinery and transport equipment), 8 (Miscellaneous manufactured articles), 95 (Armoured fighting vehicles, war firearms, ammunition, parts, n.e.s.), 96 (Coin (other than gold coin), not being legal tender). See Section 4.2 for a description of how the data was constructed.

to support strengthening Japan by absorbing Western ideas.

However, Japanese historians argue that many members of the Tokugawa shogunate had already realized in the aftermath of China's ignominious defeat in the First Opium War (1839-1842) that Japan needed a strategy to absorb Western science (Bolitho, 2007, p. 157). Early Japanese reformers, most prominently Sakuma Shozan, began developing plans for how Japan could co-exist with the West. Sakuma developed a strategy for modernizing Japan, which he summarized with the slogan "Eastern morality, Western technology." While there was little concrete action until U.S. warships entered Edo Harbor in 1853, the arrival of the Americans prompted the shogunate to spring into action. Almost immediately after the Americans arrived, the Japanese government established the Institute of Barbarian Books (*Bansho Torishirabesho*), which was tasked with developing English-Japanese dictionaries to facilitate technical translations. This project was the first step in what would become a massive government effort to codify and absorb Western science.

This section discusses the three components of Japan's technology absorption effort. First, we describe the effort to codify Western technical knowledge. Second, we demonstrate that by investing in elementary and university education, the government ensured the population had the necessary skills to absorb and apply the technical knowledge it provided. Third, we discuss how the government raised enough tax revenue to finance these costly policies.

3.2.1 The effort to codify Western technical knowledge

The key component of the Meiji technology policy studied in this paper is the large-scale state-led *codification* of technical knowledge in the Japanese language. Codification refers to the creation of a means of transmitting knowledge, through "language creation and the writing of messages," that does not require direct contact between the originator of the knowledge and the recipient (Cowan and Foray, 1997, p. 595). Technical manuals, textbooks, and scientific papers are all examples of codified knowledge, as the knowledge contained in these publications can be accessed without personal contact with the author.

Codified knowledge is cheap to reproduce and disseminate (conditional on available technologies such as printing), making it a powerful tool for knowledge diffusion (Abramovitz and David, 1996). Yet its non-rival nature gives it public good attributes, implying that the market will typically undersupply codified knowledge (Foray, 2004, p. 73). Modern scholarship on the economics of knowledge has identified multiple factors that are important for codified knowledge to be successfully absorbed. First, codification often requires prior language development (Cowan and Foray, 1997). Intuitively, it is necessary to first develop the jargon used to express new ideas. Second, accessing codified knowledge requires absorptive capacity such as literacy or basic scientific training. Cowan and Foray (1997, p. 605) describe this as follows, "Diffusion and use of codified knowledge are thus dependent on the irreversible investment required to build a community of agents, a 'clique' or a network the members of which can 'read' the code." Third, complementary investments in tacit knowledge are required (Cowan and Foray, 1997; Mokyr, 2011). Unlike codified knowledge, tacit knowledge is deeply embedded in personal experience and context; it cannot be detached and fully made explicit by the person who holds it (Polanyi, 1966). For example, consider the master spinner demonstrating the operation of a spinning machine. It is not possible to break down and codify every movement of the spinner's hands (some of which even the spinner may not be aware). As we discuss below, Meiji technology policy made all of these investments.

Language development to facilitate translation. Consistent with the discussion above, language development was a significant barrier to codifying Western science and technology in the Japanese language. Linguists and lexicographers have written extensively on the difficulty of sci-

entific translation between dissimilar languages (c.f. [Clark 2009](#); [Kokawa et al. 1994](#); [Lippert 2001](#); [Montgomery 2000](#)). Technical translation is relatively easy in languages that share the same Greek and Latin roots. Thus, a speaker of French or German can easily guess that an English technical word like “telegraph” should be translated as “télégraphe” or “telegraf,” respectively, and it would be easy for readers of all three languages to remember from their knowledge of Greek root words that telegraphs involve the transmission of words across distance.

Translation of English jargon into languages with root words not based on Greek and Latin is much harder because it requires language creation. For example, a typical speaker of Arabic would be hard-pressed to guess the meaning of the Arabic word “tiligraaf,” from its spelling any more than a typical English speaker could guess the meaning of “algebra” (which comes from the Arabic word “al-jabr”) from its spelling. People who did not understand languages closely related to English needed to translate vast amounts of English jargon to understand modern production techniques. Consistent with this, in Appendix Table [A.1](#), we provide suggestive evidence that linguistic distance was a barrier to technology diffusion and, ultimately, economic growth during this period. Specifically, we show that GDP per capita in 1870 and 1913 tended to be lower in countries and regions speaking a plurality language that was more linguistically distant from English, *conditional on physical distance*.⁸ While we do not interpret this negative relationship causally, we take it as suggestive empirical evidence consistent with scientific translations increasing technology access costs and inhibiting technology diffusion.

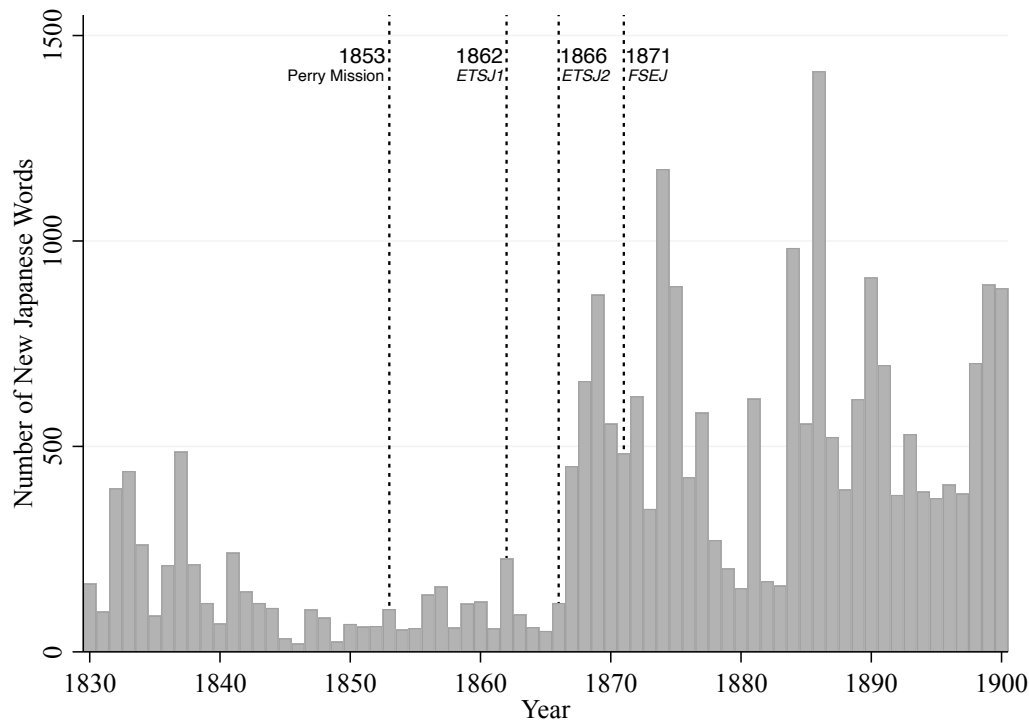
The language creation problem Japan faced in translating Western science was two-fold. First, there were no words in Japanese for IR products such as the railroad, steam engine, or telegraph, and using phonetic representations of all untranslatable jargon in a technical book resulted in transliteration, not translation. Second, translations needed to be standardized so that all translators would translate a given foreign word into the same Japanese one, a classic example of a coordination problem.

Solving these two problems became one of the Institute of Barbarian Books’ main objectives. After carefully studying how to solve these problems, Japanese translators decided to base the translation of English jargon on Chinese glyphs whose meaning was known to all literate Japanese and played a similar role as Latin and Greek words in English (c.f. [Kokawa et al. 1994](#); [Lippert 2001](#); [Clark 2009](#)). For example, in order to translate the word “telegraph,” Fukuzawa Yukichi, who would go on to become one of the most famous government translators, created the Japanese word “*denshin*” in 1866 using glyphs that combined the Chinese characters for “electric” (*den*) and “message” (*shin*). While a Japanese reader encountering the term “electric message” might not recognize that it means telegraph on the first reading, it is easy to remember it once one learns the definition. [Lippert \(2001\)](#) argues that Japanese government translators’ decision to create Japanese jargon based on Chinese root words is an important factor in making foreign scientific texts much easier to understand in Japanese than in alphabetic languages not based on Latin and Greek, where jargon is just transliterated. In other words, the Japanese government’s investment in modifying the Japanese language to accommodate new words may have been a public good that lowered the cost of accessing technology for Japanese people.

The importance of this strategy for codification was not lost on Japanese reformers. For example, Sakuma wrote of the first English-Japanese dictionary, the ETSJ (*Eiwa-Taiyaku-Shuchin-Jisho* or “A Pocket Dictionary of the English and Japanese Language”), which was published by the Institute in 1862, “I would like to see all persons in the realm thoroughly familiar with the enemy’s conditions, *something that can best be achieved by allowing them to read barbarian books as they read their own language*. There is no better way to enable them to do this than by publishing this dictionary” ([Hirakawa](#),

⁸Appendix Figures [A.5](#) and [A.6](#) show the scatterplots for this relationship.

Figure 3: Word Creation in Japanese



Note: Number of new words created in Japanese from *Nihon Kokugo Daijiten*. The dictionary contains information on the first known time a word was used in a document, which we use to construct this graph. Dashed lines refer to the Perry Mission and publication dates of English-Japanese dictionaries.

2007, p. 442, emphasis added). A much larger dictionary supplanted this small dictionary, the FSEJ (*Fuon-Sozu-Eiwa-Jii* or “An English and Japanese Dictionary”) in 1871, which contained two to three times as many words and a significant amount of English jargon.⁹

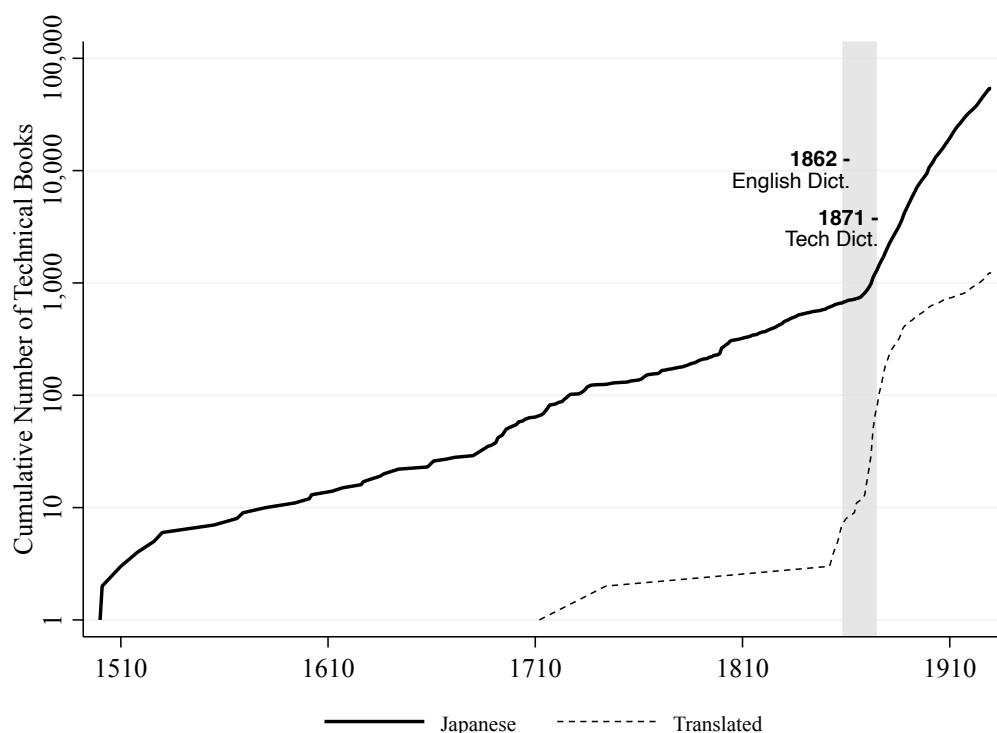
In Figure 3, we present suggestive evidence that solving the coordination problem associated with translating jargon facilitated the emergence of new words in Japanese. We obtained the first recorded use of Japanese words based on the revised edition of the *Nihon Kokugo Daijiten* (“The Unabridged Japanese Dictionary”), published by Shogakukan, encompassing 300,000 Japanese words. Word creation in Japan before the 1860s was surprisingly low—typically, only around 100 new Japanese words were created each year. Even in the first decade after Japan opened to the West following the Perry Mission, the rate of new-word creation in Japan remained essentially unchanged. This result is quite surprising given that in 1854, the Americans brought many pieces of new technology to show to the Japanese, such as a working locomotive, telegraph machine, cameras, etc. Exposing the Japanese to Western technology did not, in and of itself, lead to the emergence of new words. However, starting around the creation of the first English-Japanese dictionary (ETSJ1) in 1862 and accelerating with the large print run of this dictionary in 1866 (ETSJ2), the number of new words in Japanese rose to around 500 per year. Word creation

⁹Kokawa et al. (1994, pp. 80-119) is the source for our information on dictionaries. Publication and release dates are difficult to pinpoint exactly in this period. The Pocket Dictionary was first released in 1862 with a print run of only 200 copies but was reprinted and distributed much more widely in 1866. Similarly, the FSEJ was printed on a linotype machine in 1871 but officially published in 1873.

accelerated to over 1000 words per year following the release of the extensive English-Japanese dictionary, the FSEJ. Thus, to the extent that new word creation tracks new ways of codifying and conceptualizing the world, this evidence suggests that the government-led dictionary creation efforts in the 1860s helped solve the coordination problem inherent to introducing new ideas.

From words to books: state-led codification of technical knowledge. Alongside the public provision of dictionaries, the public sector played an outsized role in translating technical books. A search through the biographies of every person we could identify who translated a technical book between 1870 and 1885 reveals that 74 percent of the translators were government employees.¹⁰ This number is likely a lower bound because Japanese biographical dictionaries do not necessarily list every job a person held. The failure of the private sector to generate many technical translations likely reflects the fact that it was impossible for translators to prevent other authors from paraphrasing their work and publishing it independently. Thus, government intervention was required to solve the public-good problem of codified knowledge creation.

Figure 4: Codified Technical Knowledge in Japan



Note: Codified technical knowledge for each year refers to all technical books written in Japanese in the NDL catalog or any other Japanese library linked to the NDL. A book is considered “Translated” if the NDL flags the book as a translation. The y-axis is on a log scale.

What were the effects of this effort to codify technical knowledge? In Figure 4, we examine the evolution of technical knowledge in the Japanese language by scraping the catalogues of the

¹⁰The NDL catalog specifies the translator for over 200 technical books translated to Japanese in the 1870s and 80s. We searched for the names of all translators on *JapanKnowledge Lib*, an online database, and made extensive use of Ueda et al. (2003), a biographical dictionary containing entries for more than 75,000 Japanese people and Heibonsha (1974), a biographical dictionary of 30,000 people.

National Diet Library and 81 additional Japanese libraries to construct a time series of all technical books from 1500 to 1930. Between 1600 and 1860, the number of technical books in Japanese grew by 1.6 percent per year.¹¹ The rate almost sextupled to 8.8 percent per year between 1870 and 1900, starting just as staff at the Institute for Barbarian Books produced the 1862 and 1871 English-Japanese dictionaries. After centuries in which the number of technical books written in Japanese doubled every 44 years, the number suddenly began to double every eight years. In other words, Japan's emergence from its Malthusian equilibrium is associated with a massive increase in the growth rate of codified technical knowledge. We observe a significantly sharper increase in translated technical books. Japanese translators had only succeeded in translating 8 Western technical books between 1500 and 1860; by 1900, they had translated 608 books. As the figure shows, the growth rate of new technology entering Japan changed suddenly and sharply after the government produced English-Japanese dictionaries and subsidized technology absorption.

How important was the supply of codified knowledge for absorbing Western technology in Japan? Historical evidence suggests that the translation of Western technical books played a central role in developing one of Japan's most important nineteenth-century industries: cotton textiles. Consider the story of Ishikawa Masatatsu, who established Japan's first cotton textile mill. [Horie \(1960\)](#) reports that "while employing [Ishikawa as an advisor], the lord [Shimazu Nariakira] showed him a book. Because it was in English, he sent it to Nagasaki for translation into Dutch, and it turned out to be a book on the cotton spinning industry. The attention of the lord, who had been previously interested in machine spinning, was abruptly caught by the book, and the plan for building a cotton spinning mill was made... [Thus began] the Kagoshima Cotton Spinning Mill, the forerunner of the modern spinning industry in Japan, which began operation in 1867." [Braguinsky \(2015\)](#) reveals that translating the book from English, a language Ishikawa never learned, into Dutch, a language Ishikawa understood, took a whole year. As one can tell from the passage, without English-Japanese dictionaries, technical books could often not be translated directly into Japanese. This roundabout means of learning technology meant that it took eleven years from the time that Ishikawa was hired by Shimazu as a technical advisor before he could establish the mill. It is a clear case of language differences raising technology access costs and translation lowering them.

One can find numerous other examples of Japanese entrepreneurs utilizing books to inform their investment and production decisions. For example, [Tamagawa \(2002\)](#) writes, "Many large mills such as Osaka, Kanegahuchi and Kurashiki and others founded their own training schools for male workers, teaching fundamental spinning technology. The textbooks and the study aid books on cotton spinning were mainly translated versions of the Platt Bros.' catalogues and instructions."¹²

¹¹ Although "Dutch learning" was considered significant during the Tokugawa period, translating Dutch technical books appears to have been rare. Japanese libraries typically do not specify the original language of their translated books, but we found 463 foreign technical books published before 1870 in their collections. This list likely includes books purchased both before and after 1870. Among these, only 23 are in Dutch and one in Chinese. Since the importation of books in other languages was prohibited during most of the Tokugawa period under penalty of death, these figures give us an upper bound on the number of foreign technical books that entered Japan. As we will see in Figure 5, part of this is likely explainable by the paucity of technical books written in Dutch before 1870.

¹² [Meade \(2022\)](#) provides details on the specific machines and methods described in translated books on textiles: "Translated works tended to be used in industry and in other training institutions where teaching was not carried out by foreign employees. Reflecting its importance to the Japanese economy at the time, textiles were the focus of a considerable number of translations during the Meiji Period. Among translations on textiles were Meriyasu Orikata (1873), a translation of Dana Bickford's *Illustrated Instructions for Setting Up and Running the Bickford Family Knitting Machine* (1871), *Senko Shinsho Kagaku Jikken* (Chemical

3.3 Codification in the West, the periphery, and Japan

Although Japan was not unique in translating technical books, Japan was unique among countries in the periphery of the IR in the scale of its translation project. We demonstrate this by constructing a novel database of the amount of codified technical knowledge available in local vernaculars each year for 33 languages, encompassing the 20 languages with the most speakers. We define the set of books containing technical knowledge as those with a subject that can be classified as applied sciences, industry, technology, commerce, and agriculture. We exclude books on theoretical technical knowledge, such as books in the hard sciences or subjects that do not directly benefit firms (e.g., medicine). After defining a common set of subject codes, we scraped the catalogs of national or other major libraries for books in the vernacular published in each year and report cumulative totals for each language (See Appendix K for details).

For many major European and Asian languages (e.g., English, French, German, Chinese, and Japanese), we scraped the national libraries of countries where the language is the native tongue of a substantial fraction of the population (so we restrict ourselves to only using the National Diet Library collection for Japan in this plot). For many other languages (such as Arabic and Russian), we could not find a scrapable national library. Instead, we scraped WorldCat, an online catalog of over 15,000 libraries worldwide covering dozens of languages. Using the publication year of each book in our sample, we construct the time series of codified knowledge by spoken language. This yields what, to the best of our knowledge, is the first systematic dataset on codified technical knowledge available in the vernacular for major languages.

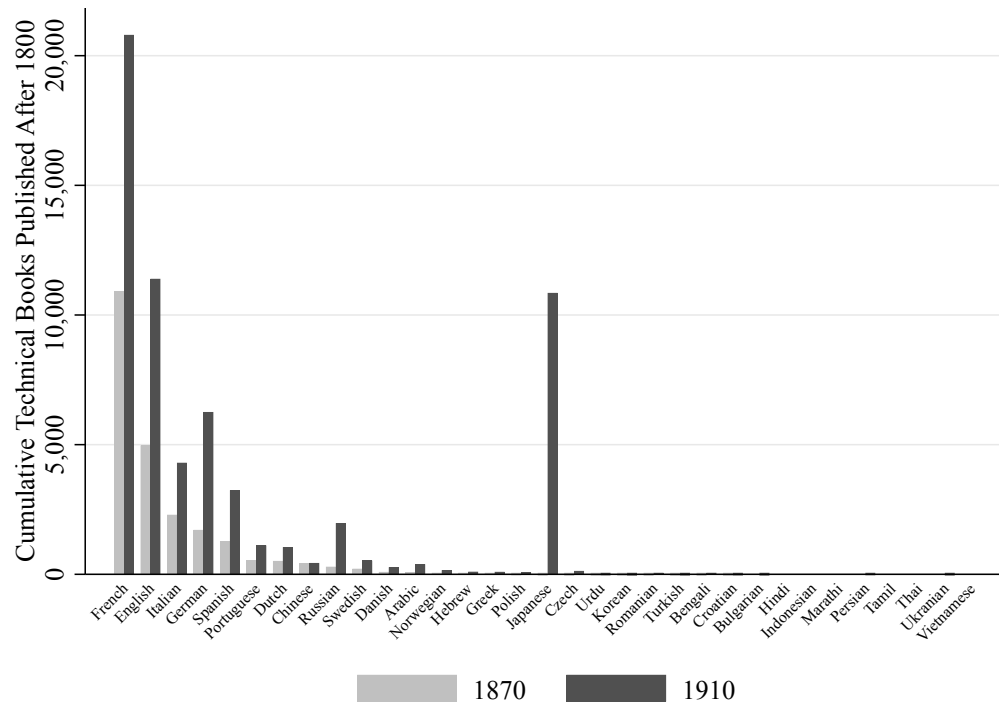
Despite Japan's rapid progress in codification at the end of the nineteenth century, the level of Japanese codification in 1870 was quite ordinary. Figure 5 presents the extent of codification of technical knowledge in 1870 and 1910. Two features of the data stand out. First, in 1870, 84 percent of all technical books were written in four languages: English, French, German, and Italian.¹³ This puts into comparative perspective the achievements of the Enlightenment. There was little to no codification in any non-European language, meaning that people who could not speak European languages were technically illiterate. Second, this figure also puts into comparative perspective the achievements of Japan's public provision of technical knowledge *after* 1870. Starting from a level in 1870 that was comparable to other languages spoken in the global periphery, by 1910, Japan had amassed a body of codified technical knowledge comparable to that of the languages of the Enlightenment. Moreover, nowhere else in the global periphery do we see a similar increase in codified technical knowledge. This suggests that outside of the set of countries contributing to the Enlightenment, codified technical knowledge only appeared with state intervention.

These findings motivate our empirical strategy. Understanding the effects of codifying technical knowledge on economic outcomes such as productivity growth is typically difficult—codification in most settings happened gradually over time, making it hard to rule out other explanations. The swift creation of codified technical knowledge in Japan, however, creates two relatively well-demarcated periods: one in which Japan had no access to technical knowledge, and one in which it did.

Experiments in Dyeing, 1878), Seiyō Senshoku Ho (Western Dyeing Methods, 1878) and Seiyō Sarasa Senhoshō (Western Cotton Dyeing Methods, 1879).” [pp. 13-14]

¹³We probably underestimate codification in English because we could not scrape the British Library, which suffered a cyber attack in 2023, resulting in security measures that prevented us from scraping it. Our data for English is from the Library of Congress, which provides a measure of technical books written in English and available outside of England.

Figure 5: Codified Technical Knowledge in Major World Languages



Note: Technical knowledge is measured as the number of books in the following subjects: agriculture, applied sciences, commerce, industry, and technology. The languages are ordered based on the total number of technical books published up to and including 1870.

3.4 Investment in Absorptive Capacity: Education Policies

Beyond spending on technology policies directly, the Meiji government also deployed education policies. As discussed above, these investments increased the absorptive capacity of the Japanese economy by creating a large network of individuals who could read and understand the codified knowledge. Compulsory elementary school education began in 1872, although most Japanese parents refused to send their children to government schools because, in the words of an 1877 Ministry of Education report, the “people do not yet see education as useful and parents are complaining” (Rubinger, 2000, p. 170). Government pressure quickly overcame the anti-education attitude of non-elite Japanese. The fraction of boys and girls attending school rose from 39.9 percent of eligible boys and 15.1 percent of eligible girls in 1874 to 58.2 percent of boys and 22.6 percent of girls by 1879. By 1890, 90.6 percent of boys and 71.7 percent of girls were enrolled in elementary school (National Institute for Educational Policy Research, 2011). Since child labor was common during this period, many of these elementary school graduates would have been in the labor force by the time they were teenagers.

These schools offered high-quality education by the international standards of the day. Notably, the national curriculum stipulated that over eight years of elementary education, no less than forty percent of class time should be allocated to scientific subjects – more than any other country at the time (Itakura, 2009; quoted in Meade, 2024, p. 230). Rubinger (2000) argues that data from mandatory intake examinations for Japanese army conscripts provide a representative sample of young Japanese males that we can use to assess educational levels. If one defines literacy as

being able to write a formal letter in Japanese as judged by the Imperial Japanese Army, new conscripts in all but one of Japan's forty-seven prefectures in 1909 had literacy rates above 90 percent. Mathematics education was equally impressive. Conscripts who had completed six years of education were expected to answer word problems that required them to know algebra in order to solve, and those with eight years of education were expected to be able to compute bond yields. In other words, by the 1880s, most young Japanese men could have read technical books.

The Meiji government also pursued a conscious policy of building a modern, Western-oriented technical higher education system, which was to aid industrialization by producing technically and scientifically educated technicians and engineers (Pauer and Mathias, 2022). The Japanese government faced a complex problem in building a technical higher education system because there were almost no Japanese with advanced knowledge of STEM fields. To alleviate this problem, the Japanese hired foreign instructors to design the curriculum and teach. For example, the Japanese Imperial College of Engineering, founded in 1871, was headed by a young Scottish engineer, Henry Dyer, who had studied under William J. M. Rankine in Glasgow. The language of instruction was English, and pupils studied from a canonical set of engineering manuals published by Rankine in Britain in the middle of the 19th century (Meade, 2024) (See Table A.2). The new universities specialized in practical disciplines like foreign languages, medicine, engineering, mathematics, physics, law, chemistry, and management (Ministry of Education, 1980). Additionally, there was an emphasis on practical training with students spending long internships in mines and other companies (Pauer and Mathias, 2022).

Educated engineers appear to have had an impact on the production technologies used in Japan. Braguinsky (2015) provides econometric evidence that technical training led cotton mills to adopt different production techniques. He compares methods used in cotton mills that employed at least one college-educated engineer (who would have had to read technical manuals as part of his training) with those that did not. Using Japanese data from 1893 and 1898, he finds that Japanese mills with engineers used more Indian and US cotton, implemented different cotton mixing techniques, and had higher capital-to-labor ratios, a higher female-to-male operative ratio, many more spindles, higher TFP, and greater returns on assets.

3.5 Investments in Tacit Knowledge: “Live machines” and study-abroad missions

Alongside Meiji Japan's extensive efforts to codify technical knowledge in Japanese, the government also pursued a set of complementary policies that were well-suited to acquiring tacit knowledge. As a Tokugawa government foreign purchasing agent noted, it was important not just to ship back “a dead machine but [also] a live machine [i.e., a foreign instructor]” (Jones, 1980, p. 125). This practice became the start of a major program in which the Japanese government hired 2,400 foreigners to come to Japan as instructors or advisors. The foreigners hired by the government provided Japan with 9,506 person-years of technical training, of which over half was deployed either in educational institutions or in ministries that oversaw the building of Japan's transportation, telegraph, postal, gas, electrical, sewage, and water-supply networks. Fifty-nine percent of the training was conducted by individuals whose native language was English, 17 percent by those from France and Belgium, and 13 percent by those from Germany. The revealed preferences of the Japanese government in choosing instructors suggest that they viewed instructors whose native languages were English, and to a lesser extent, French and German, as the primary sources of advanced Western technology. As we showed above, these languages contained the most codified technical knowledge. The government not only financed foreigners to come to Japan but also paid for Japanese to study abroad. For example, in 1871, the government sent around one hundred

officials and students abroad for two years on the “Iwakura Mission” to study Western society and technology and return with a wealth of knowledge and books. In addition to this high-profile study mission, the government subsidized many other Japanese to study abroad. Foreign study trips accounted for up to 0.20 percent of annual government expenditures in the 1870s (Jones, 1980, Table 7). By facilitating direct exposure to foreign expertise, foreign production facilities, and foreign technologies, the Japanese government lowered the access costs of tacit knowledge.

3.6 Paying For The Technology Transfer Policies

One may wonder how the Meiji government was able to raise enough government revenue to fund these policies. Real government expenditures tripled between 1871 and 1874 (See Appendix A for details on the sources for numbers presented in this section). Paying for the foreign workers alone required substantial expenditures—equalling about 2 percent of total government expenditures in 1876, one-third of the University of Tokyo budget, one-half of the Ministry of Education budget, and in 1879, two-thirds of the public works budget (Jones, 1980, p. 13). The key to Japan’s newfound ability to pay for these programs was the 1873 Land Tax Reform Ordinance, which Japanese economic historians have called “the single most important reform of the Meiji Restoration,” (Hayami, 1975, p. 47). Interestingly, the idea of instituting a land tax had its origin in the work of government translators in the 1860s. As Yamamura (1986) discusses in detail, Kanda Takahira, a high-ranking Meiji official who had translated a book on economics in the Tokugawa period, realized that Japan could raise enormous amounts of tax revenue with limited efficiency loss by instituting a heavy land tax, as opposed to the earlier output tax.¹⁴

One way to gauge the magnitude of Japan’s investment in learning is by comparing it to China. By 1884, the land tax measures had given Japan an eight-to-one advantage in per-capita taxation relative to China, which enabled Japan to finance human capital investments and public goods at a rate that Chinese reformers could only dream about.¹⁵ Put differently, Japanese government expenditures (taken from Ohkawa et al. (1965)) on education alone amounted to 11 percent of the budget in 1880. In other words, if China had attempted to implement only the education component of the Meiji reform package, it would have had virtually nothing left over for any other government functions.

4 Data

One of our main contentions is that, relative to other regions in the periphery, Japan made a uniquely large investment in codification that enabled its firms to rapidly assimilate British technology and increase productivity in the sectors that stood to gain from IR technologies. Testing this hypothesis requires us to construct several novel datasets. In this section, we describe the primary datasets used in the empirical analysis. First, we discuss how we quantify the British supply of codified technical knowledge by sector. Second, we create a bilateral industry export dataset that enables us to examine whether codification shifted comparative advantage towards sectors that benefited most from IR technologies. The appendix contains a complete discussion of

¹⁴Although agricultural taxes before the Meiji period were called “land taxes,” they were closer to output taxes in implementation. As Ohno (2018, p. 39) writes, “A new land tax at the initial rate of 3 percent of the assessed land value replaced the old rice tax that was levied on the annual yield of rice.”

¹⁵Wong (2012) reports that Chinese tax revenue in 1884 was 77 million silver taels. We converted it into yen in two ways. The number in the text uses the exchange rate series from Fouquin and Hugot (2016) of 1.39. We obtain a similar estimate if we convert silver taels into yen by noting that an 1867 Shanghai silver tael contained 36.0 grams of silver and an 1876 silver yen coin contained 24.3 grams of silver, according to <https://en.numista.com>. This implies an exchange rate of 1.48 yen per tael.

all data used, including all data construction steps and sources.

4.1 Constructing the British Patent Relevance measure

A key challenge for this paper is to quantify the supply of codified technical knowledge available to Japan and other regions by industry. We utilize textual information from one of the primary channels through which codified technical knowledge was disseminated during this period: the translation and publication of technical manuals. Nineteenth-century technical manuals give detailed, practical descriptions of the technological and organizational aspects of an industry. Their audience was the practitioner, the entrepreneur setting up a plant, or the manager overseeing production. Their value lay in the fact that they contained precisely the type of technical knowledge entrepreneurs would need to familiarize themselves with for the setting up of modern, factory-based manufacturing, as well as for its day-to-day operation.

Our aim is to quantify the amount of new, IR technical knowledge contained in these technical manuals that could be used in different industries. The main textual source we use to identify *codifiable* IR technologies is the corpus of British patent synopses (1780-1852). Using natural language processing (NLP), we compare the textual similarity between IR patents and technical manuals within each industry. If IR technologies are more relevant for an industry, then the jargon used in the corpus of IR patents should be more similar to the jargon used in manuals used to describe production techniques in that industry.

Before describing each data source and the NLP pipeline below, we first make four broader comments about our approach. First, given industry differences in the propensity to patent (Moser, 2005), our choice of patent synopses as the corpus of codifiable innovations requires some justification. We focus on patents as a proxy for innovation because we are interested in capturing the supply of *codified* innovation, which can diffuse at a distance, as opposed to all innovation. Previous work has argued that technology diffuses when the patent system creates a market for innovation – in fact, one rationale for the patent system is to diffuse technologies (Lamoreaux and Sokoloff, 1999). There is some supporting causal empirical evidence showing that patent protection leads to greater geographic diffusion of innovation (Moser, 2011).

Consistent with patents being an important direct source of knowledge for technological follower countries, the Japanese Patent Office collected summaries of British, U.S., French, and German patents (Smethurst, 2007).¹⁶ Importantly, measuring the supply of codifiable innovations in this way excludes two types of innovation: tacit knowledge and knowledge protected by secrecy. We view both omissions as features of our approach to measuring codifiable knowledge, rather than bugs. Tacit knowledge cannot, by definition, be codified; hence, it cannot be transmitted via technical translation. By its very nature, knowledge protected via secrecy is also much more difficult to diffuse at a distance (as shown for the chemical industry in Moser (2011)).

Second, our focus on *First* Industrial Revolution technologies (as opposed to newer technologies that were available by 1880) is motivated by the technology adoption lags literature, which documents substantial cross-country lags in technology adoption. On average, countries adopt technologies with a 45-year lag relative to their invention (Comin and Hobijn, 2010). For Japan and the rest of the global periphery, the period between 1880 and WWI (our sample period) was a time when entering and mastering IR technologies remained the primary goal (e.g., DeLong (2022)). To take just one prominent and well-studied example, in 1911, Britain and the US alone accounted for

¹⁶For example, Doi (1980, p. 2) reports that a Japanese commissioner of patents visiting Washington in 1900 to study the U.S. system stated: “We have looked about us to see what nations are the greatest, so that we can be like them... We said, ‘What is it that makes the United States such a great nation?’ and we investigated and found that it was patents.”

61% of installed factory spindles in cotton spinning, while the entire global periphery accounted for only 22% (calculations based on the [U.S. House of Representatives, Tariff Board \(1912\)](#)). That is, getting factory-based, mechanized textile manufacturing off the ground (which England achieved early in the 19th century) remained a central goal for most periphery economies well into the 20th century. In Appendix B, we discuss additional historical evidence that shows why Japanese industry was not ready to absorb newer technologies until it had mastered IR technologies.

Third, we focus on *British* patents because Britain is generally perceived as the technological leader during the IR ([Broadberry, 1994](#); [Crafts, 1998](#); [Rosenberger et al., 2024](#)).¹⁷ The historical record also supports these findings for Japan. For example, [Meade \(2022\)](#) finds that the textbooks Japanese engineering students were reading in the 1870s and 1880s were heavily skewed towards British textbooks published in the middle of the nineteenth century. In addition, the Japanese government largely hired British instructors to teach in their engineering universities, and these instructors used British books.

Fourth, we focus on manuals written in English due to Britain’s centrality in IR technologies, Japan’s choice of instructors, and to prevent endogeneity bias from arising from Japanese translators translating more jargon in sectors particularly important to Japan. In addition, [Shimizu \(2010\)](#) reports that where data is available, a large majority of Japanese students studying foreign languages in public and private schools were learning English. Finally, the absence of *any* large French-Japanese or German-Japanese dictionaries published before the twentieth century would have made it relatively difficult for Japanese translators to translate technical documents written in French or German.¹⁸

4.1.1 Source Data For Technical Manuals

We hand-curated a sample of English-language technical manuals covering SITC3 Rev 2 industries published in the middle of the 19th century from *HathiTrust Digital Library*.¹⁹ We tried to select a few books (or sections of books) for each industry that contained a detailed description of the techniques. We faced two issues when selecting books: sometimes they were more general than the SITC code, and other times they were narrower. We attempted to balance these considerations by using only relevant chapters when books were general, or selecting multiple books when manuals were narrow.²⁰

Table 1 shows a random sample of the 460 books we selected from the *HathiTrust Digital*

¹⁷More precisely, while recent empirical evidence suggests Britain did not have the technological lead in *all* sectors ([Hallmann et al., 2021](#)), the sectors Britain did lead in were the ones more central in the innovation network, such as steam engines ([Rosenberger et al., 2024](#)).

¹⁸[Garnier \(2013\)](#) notes that “Between 1888 and 1905 no less than seven bilingual [French-Japanese] dictionaries were published: four French-Japanese and three Japanese-French. The three dictionaries published prior to 1900 remained small in size, containing between two and three hundred pages. Despite calling themselves ‘dictionaries,’ they more closely resembled glossaries which sought, according to the term used in their title, to present ‘common words.’” The first German-Japanese dictionary we could find in the NDL that contained more than 200 pages was published in 1904.

¹⁹Ninety percent of all technical books in our sample were written before 1883, and ninety percent of the books were published after 1838. We made exceptions only when we were unable to find a book within this time period. None of our books was published before 1806 or after 1900.

²⁰For example, a treatise on metalliferous minerals and mining by D. C. Davies (1880) was relevant to both the copper and tin industries. In this case, we chose the chapter on copper mining for the copper industry and the chapter on tin mining for the tin industry. For copper, these chapters were then supplemented with books like Piggot’s (1858) “The chemistry and metallurgy of copper” and Goodyear’s 1865 translation of “A treatise on the assaying of lead, copper, silver, gold, and mercury,” which was originally written in German.

Table 1: Random Sample of Book Titles from the *HathiTrust Digital Library*

SITC	Industry Description	Book Title
232	Natural rubber latex; rubber...	India rubber and gutta...
786	Trailers, and other vehicles,...	A complete guide for coach...
112	Alcoholic beverages	Hops; their cultivation,...
023	Butter	Butter, its analysis and...
764	Telecommunication equipment,...	The speaking telephone,...
882	Photographic and...	On the production of positive...
263	Cotton	Cotton in the middle states :...
274	Sulphur and unroasted iron...	A theoretical and practical...
271	Fertilizers, crude	American manures; and...
897	Gold, silver ware, jewelry...	Diamonds and precious stones,...
098	Edible products and...	Peterson's preserving,...
898	Musical instruments, parts...	Musical instruments ...
553	Perfumery, cosmetics, toilet...	A practical guide for the...
212	Furskins, raw	The trapper's guide: a manual...
046	Meal and flour of wheat and...	The American miller, and...
844	Under garments of textile...	Garment making a treatise,...
641	Paper and paperboard	Paper & paper making ancient...
664	Glass	The art of glass-blowing, or,...
268	Wool and other animal hair...	Sheep husbandry; with an...
061	Sugar and honey	The Chinese sugar-cane; its...

Note: This table provides a sample of books we used describing the technology in each industry. We randomly picked 20 industries, and for each industry, we randomly picked one of the books assigned to it.

(a) Unigrams

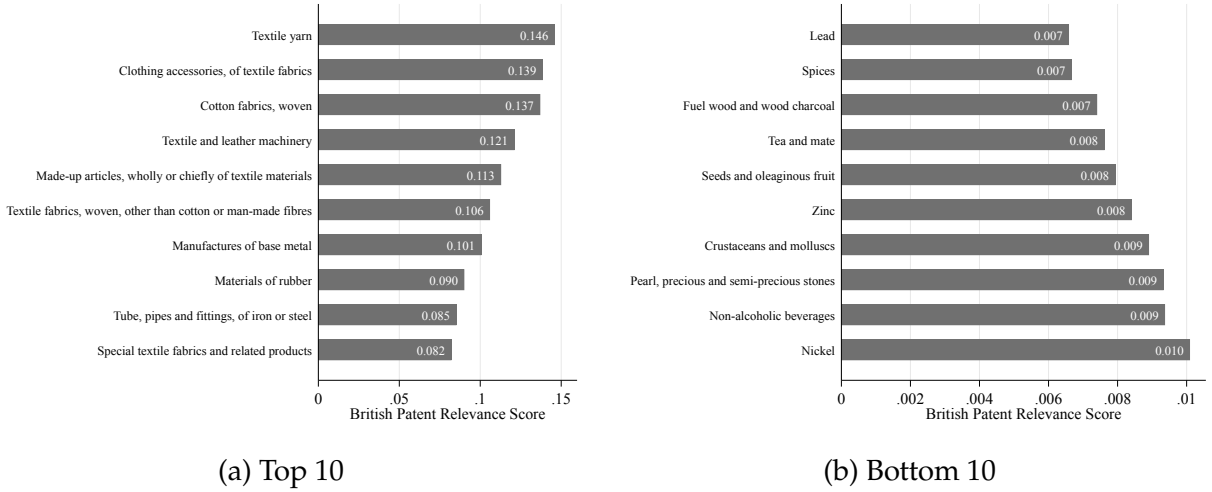
(b) Bigrams

4.1.2 Source Data for Patents

We check the robustness of our results to using British patents from later periods (1853-1879) using the full text of British patents 1853-1879 from [Coluccia and Dossi \(2025\)](#). We also conduct robustness exercises using U.S. patent text from the period 1836 (the earliest date available) to 1879.²² We webscraped the patent text from *Google Patents*, which provides digitized versions of all U.S. patents building on the tool developed by [Kelly et al. \(2021\)](#). Appendix I contains a detailed

²²We also tried to include German patent data to explore another potential technological frontier. Unfortunately, German patent descriptions are only reliably available starting from 1877, which means there is insufficient coverage before 1880 (the beginning of our trade data). Additionally, the available German patent data showed large yearly fluctuations, raising questions about their reliability.

Figure 9: Industries Ranked by British Patent Relevance



phrases that are similar to those in British patent synopses, IR technologies are likely relevant for the industry. The standard metric for measuring the similarity of two texts (documents) in NLP is cosine similarity, which motivates our adoption of this measure. In our setup, it equals the cosine of the angle between the vector representation of the word frequencies in manuals and the frequencies in patent synopses. Formally, the cosine similarity between the vectorized Bennett Woodcroft patent text BW and the vectorized technical manuals TM_i for industry i is

$$BPR_i \equiv \frac{BW \cdot TM_i}{\|BW\| \|TM_i\|} = \frac{\sum_{j=1}^n BW_j TM_{ij}}{\sqrt{\sum_{j=1}^n BW_j^2} \sqrt{\sum_{j=1}^n TM_{ij}^2}}, \quad (1)$$

which we call *British Patent Relevance (BPR)* because it measures the relevance of knowledge contained in British patents for each industry. Figure 9 plots the bar chart for the industries with the ten highest and lowest cosine-similarity scores. Reassuringly, high BPR industries include textile, footwear, machinery, and manufactured intermediate-input sectors, whereas low BPR industries contain mostly unprocessed raw materials, which were largely unaffected by IR technology.

Our measure has several advantages for our setting. Most importantly, focusing on knowledge codified in technical manuals captures one of the key channels through which nineteenth-century Japan acquired Western knowledge: the translation of these documents. Moreover, this measure naturally accounts for how a given technology benefited different industries through input-output linkages. For example, since industries that make use of steam engines will likely have technical manuals that use the bigram “steam engine,” our cosine-similarity measure will naturally quantify which industries benefited more from steam engines—a distinct advantage relative to using the industry classification of patents as a measure of relevance which only match the final output sector with patents about making that final output.

4.2 Cross-region, bilateral, industry level trade flows

We construct the first cross-region dataset of harmonized, bilateral, industry-level trade flows quinquennially for 1880-1910 using detailed historical trade records for Japan, the United States,

Belgium, and Italy (“reporting countries,” henceforth).²³

We combine existing, region-specific data sources and add newly digitized trade data from various sources. Specifically, we digitized data on US trade flows (exports and imports), Japanese exports for 1875, and quinquennial Japanese imports between 1875 and 1910. We use existing data on Belgian exports and imports in manufacturing from [Huberman et al. \(2017\)](#); on Japanese exports from [Meissner and Tang \(2018\)](#); and on Italian exports and imports (for major trading partners only) from [Federico et al. \(2011\)](#).²⁴ An observation in this dataset, x_{ijkt} , refers to an export flow in sector k from origin i to destination j reported in year t . Using the fact that an export flow from i to j is equivalent, in theory, to imports from j to i , we can use import flows from reporting countries for unobserved regions’ export flows.

Japanese trade data does not include its colonies, so Japanese territorial expansion over this period does not affect our results. We define the set of non-Japanese Asian Regions (ASIA) as French East Indies, Hong Kong, China, Korea, Portuguese East Indies, Siam, Straights Settlements, and India. We used the Maddison data to divide the set of *non-Japanese* exporters into three terciles—High (H), Medium (M), and low (L)—according to estimated GDP per capita in 1870. For regions that do not correspond to modern countries, we use the average GDP per capita of the countries in that region.

We harmonized product lines in a manner consistent with the other pre-existing data sources used in the dataset. We conducted extensive validation exercises to ensure that similar product lines were consistently concordered to the same three-digit SITC category across all datasets (see Appendix G.1 for details). Region names (and boundaries) were harmonized within and across datasets. All trade values were converted to yen (at current exchange rates) using historical exchange rates from [Fouquin and Hugot \(2016\)](#). Our dataset consists of export values for 37 regions in 93 industries. Appendix Table A.3 contains the summary statistics.

5 Codification and Development

The previous sections established that 1) Japan experienced unique shifts in its export composition between 1880 and 1910, mainly driven by its manufacturing sectors, and 2) Japan was unique among peripheral economies in providing its citizens with access to codified technical knowledge in their vernacular. This section presents empirical evidence consistent with a causal relationship between these two aspects of Meiji Japan’s economy.

Our empirical approach relies on industry-level variation in the extent to which the codification of technical knowledge affected export growth. Intuitively, would-be entrepreneurs of textile yarn, which had undergone enormous changes in production methods during the FIR, had large productivity benefits to reap from access to technical knowledge. In contrast, producers of raw commodities such as nickel, zinc, or lead—the production of which was barely affected by IR technologies—had far fewer productivity benefits to reap from reading technical knowledge. We

²³Recent years have seen a proliferation of high-quality, cross-country, bilateral trade datasets (see, e.g., [Fouquin and Hugot 2016](#); [Pascali 2017](#); [Xu 2022](#)). Yet because these data are not disaggregated by industry, they cannot be used for our purposes.

²⁴We do not include Germany’s digitized trade data in the combined dataset because Germany’s historical trade statistics before 1906 present several distinct methodological challenges that make comparisons over time and across countries difficult ([Hungerland and Wolf, 2022](#)). First, until 1888, some parts of the German Empire were not part of the German customs union and maintained their own records, making it challenging to construct a single dataset covering all German trade. Second, during our sample period, the classification scheme for products was repeatedly revised: at different points in time, between 400-1,200 distinct products were listed, making it difficult to construct a consistent classification over time (see [Hungerland and Wolf \(2022, Figure 6A\)](#)).

operationalize the extent to which an industry could benefit from access to technical knowledge using the British Patent Relevance (BPR) measure introduced in Section 4.1.

5.1 Cross-Sectional Evidence

We test this relationship by estimating regressions of the form

$$g_{ik} = \alpha_i + \beta_J * BPR_k \times I_{iJ} + \beta_r * BPR_k \times I_{ir} + \epsilon_{ik}, \quad (2)$$

where g_{ik} is the average annual export growth in region i and industry k ; α_i is an exporter fixed effect; BPR_k is the British patent relevance measure for sector k ; I_{iJ} is a dummy that equals one if i is Japan; I_{ir} is a dummy that equals one if i is part of some other regional grouping r ; β_J and β_r are estimated parameters; and ϵ_{ik} is an error term. We partition the regions in our sample into mutually exclusive regions to probe potential confounders.

Since BPR_k is *not* Japan-specific, our measure of British Patent Relevance captures the world *supply* of technical industry-level knowledge. This is important, as our measure is not based on what was written in Japanese, which would be endogenous if the government or entrepreneurs strategically generated knowledge for sectors more likely to succeed.

We hypothesize that $\beta_J > 0$; that is, Japanese industries that benefited more from knowledge codification experienced faster export growth in Japan. Column (1) in Table 2 shows the results from estimating this regression for just the sample of Japanese industries. Appendix Figure A.7 presents the corresponding scatterplot. Consistent with our hypothesis, industries with a higher BPR_k experienced faster export growth during the sample period. The coefficient is both economically meaningful and highly statistically significant. Since we standardize BPR in all specifications, our estimates imply that a Japanese industry with a one-standard-deviation higher British Patent Relevance measure experienced export growth that was 12 percentage points per year faster. These large effects help account for the sudden shift in Japanese exports from primary products to manufactured goods.

A causal interpretation of the parameter of interest, β_J , requires that BPR_k is uncorrelated with the error term ϵ_{Jk} . The main concern in this context is omitted-variable bias: unobserved factors correlated with BPR_k drive the pattern of productivity growth in Japan. For example, it may be that British Patent Relevance mattered not just in Japan but in all regions during the nineteenth century. Alternatively, it is conceivable that BPR_k is correlated with distance to the technology frontier. In this case, Japan's experience might be similar to that of medium- or low-income countries. Finally, it is also possible that some other Japan-specific factors, such as fundamental comparative advantage or institutional reforms implemented during the Meiji Restoration, are correlated with BPR_k . We tackle the various threats to identification using three strategies.

First, we exploit the fact that we know which countries codified and can measure industry performance around the world to examine the relationship between BPR_k and export growth in a pooled sample that includes all industry-region pairs for which we have data. Column (2) shows that, on average, other regions in our sample did not exhibit the same pattern of export growth that we found for Japan. Export growth in this period is *negatively* and statistically significantly correlated with BPR_k in countries other than Japan. In other words, the association between Japan's export growth pattern and the amount it stood to learn from British patents is not common to all regions.

Second, if codification was the key difference across countries, we should expect a positive relationship for regions with access to codified knowledge. Indeed, in columns (3) and (4), we see that British Patent Relevance is significantly correlated with faster export growth rates in regions speaking languages with the largest numbers of technical books (English and French) relative to

Table 2: Annualized Export Growth and British Patent Relevance

	Export Growth						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
BPR $\times$ Japan	0.121*** (0.033)	0.121*** (0.033)	0.121*** (0.033)	0.121*** (0.033)	0.121*** (0.033)	0.121*** (0.033)	0.121*** (0.033)
BPR $\times$ Not Japan		-0.030*** (0.009)	-0.037*** (0.010)	-0.037*** (0.011)	-0.070*** (0.016)		
BPR $\times$ English-Speaking			0.042** (0.020)				
BPR $\times$ French-Speaking				0.032** (0.016)			
BPR $\times$ Top-4 Codified					0.078*** (0.018)		
BPR $\times$ High-Income						-0.460 (0.307)	-0.460 (0.307)
BPR $\times$ Medium-Income						-1.166 (0.748)	-1.024 (0.764)
BPR $\times$ Low-Income						-2.093*** (0.680)	-1.410* (0.850)
BPR $\times$ Asia							-1.443 (1.094)
Observations	71	1395	1395	1395	1395	1395	1395
R^2	0.112	0.233	0.234	0.234	0.243	0.236	0.236
Country fixed effects	✓	✓	✓	✓	✓	✓	✓
Sample	Japan	All	All	All	All	All	All

Note: The dependent variable, “Export Growth,” is the annualized export growth rate for a region i ’s industry k between {1880,1885} and {1905,1910}. BPR stands for “British Patent Relevance” and captures how relevant British patents are to the vocabulary used in the manuals of industry k . BPR is standardized to have a mean of 0 and a standard deviation of 1. “Japan” is a dummy variable that equals one if the region is Japan and zero otherwise. “Not Japan” is analogously defined. “English-speaking” is an indicator equal to 1 if the region’s plurality language is English. “Top-4 Codified” is a dummy for countries that speak one of the 4 most codified languages: French, English, German, or Italian. {High, Medium, Low}-Income are dummies that equal one when a region is in the top third of the income distribution (High), middle third (Medium), or bottom third (Low) according to the Maddison per capita GDP data; we set these dummies to 0 for Japan. The Asia dummy equals one if the region is in Asia and zero if it is Japan or not in Asia. Robust standard errors in parentheses: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

those that do not. In column (5), we try to deal with the imprecision of estimating the impact of codification by pooling across the four languages with the most codification in 1870 (French, English, Italian, and German) and find that Japan and the other top-4 codifiers all experienced faster export growth in sectors that stood the most to gain from codified technical knowledge

relative to regions that did not codify. Taking these results together, we conclude that Japan and European codifiers' export growth shows similar patterns.²⁵

Third, we explore the possibility that Japan's experience was a product of its income level or geography in columns (6) and (7). We group countries by income tercile (column 6) and isolate Asia (column 7). No region group displays a similar productivity pattern. On the contrary, the poorest countries, particularly in Asia outside of Japan, show a negative correlation, though the patterns are never consistently statistically different from zero. In summary, the pooled specifications suggest that Japan's export growth pattern was unusual for a peripheral economy but closely aligned with other codifiers. Regional trends or structural factors, such as distance to the technology frontier, are unlikely to explain the relationship.

5.2 Time Series Evidence

The cross-sectional evidence established that Japan's pattern of technological acquisition was similar to that of other codifiers but differed from that of other countries in the periphery, but it leaves open the question of whether this difference was due to codification *per se* or reflects an unobserved Japan-specific characteristic. For example, perhaps some unobserved common geographic characteristic, like coal deposits, explains the commonalities observed among codifying countries. Alternatively, Tokugawa literacy, culture, living standards, or any of a host of unique Japanese characteristics might explain their ability to absorb Western technology at this time.²⁶ Finally, many of the Meiji government reforms were gradually transforming the Japanese economy. Perhaps it was one of these and not codification that explains Japan's transformation.

Section 3 established that the change in the composition of exports towards manufactures happened rapidly and immediately after Japanese entrepreneurs had access to technical knowledge in their vernacular. While we have argued that the sudden timing of this change suggests it was not the result of a slow-moving process like the share of literate Japanese, the results of the previous section suggest that we could implement a more powerful test of the hypothesis that codification was crucial for understanding Japanese economic development. We showed that British patenting caused exports to grow *faster* in industries that heavily used IR technologies in codifying regions and *slower* in non-codifying ones. If codification is the key to Japanese development, then we should expect to see the same pattern in Japanese data as the country shifted from being a non-codifying country to a codifying one. However, if some uniquely Japanese characteristic explains the shift in Japan's export patterns, we should expect Japan's export pattern to shift at a constant or gradually changing rate throughout the sample period.

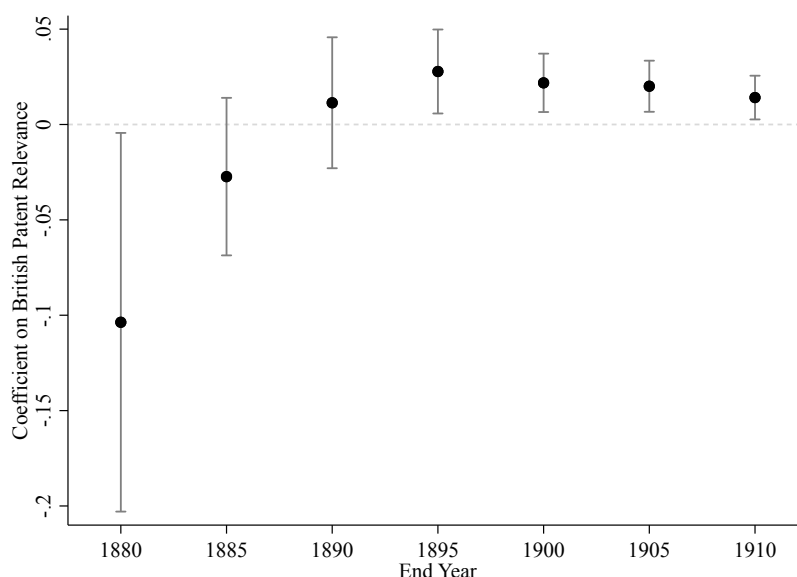
We now test whether Japan's sudden achievement of technical literacy coincides with a reversal in the relationship between export growth and BPR. It is not possible to pinpoint a specific year when Japan became technically literate, but the data suggest it likely occurred in the 1880s. For example, in 1880, there were only half as many technical books in Japanese as had existed in Spanish in 1870. Thus, in 1880, Japan was still a minor codifier compared to the major European codifiers. Between 1880 and 1890, however, the number of Japanese technical books in the National Diet Library grew from 706 to 2,823, surpassing the 1870 number of codified books in every European language except English and French.

We test how British Patent Relevance affected shifts in Japanese comparative advantage by

²⁵The estimated coefficients for Japan are larger (although not always significantly so) than those for regions in which a plurality speaks a codified European language. This makes sense given that Japan's late industrialization implies it had more to learn from British patents.

²⁶For example, some authors have pointed to Tokugawa literacy rates as a possible explanation for the ease with which Japan adopted foreign technologies in the Meiji period ([Koyama and Rubin, 2022](#)).

Figure 10: Coefficients from Regressing Japanese Export Growth on BPR by End Year



Note: We plot the estimated coefficient on BPR as well as the 95% confidence interval in a regression of Japanese industry export growth from 1875 to the year displayed in the figure on BPR.

regressing annualized Japanese industry export growth rates from 1875 to an end year that varies in 5-year increments starting in 1880. Figure 10 plots the estimated coefficients from these regressions, along with the 95% confidence intervals.²⁷ We interpret the specification for export growth between 1875 and 1880 as a placebo exercise that examines the relationship between export growth and BPR in the years before Japan achieved technical literacy. We obtain a negative and significant coefficient on BPR, indicating that Japanese export growth was slower in industries that benefited the most from the IR. This result is similar to what we saw in Table 2 for non-codifying regions. In other words, before Japan became technically literate, its export growth patterns resembled those of other countries in the global periphery: lower export growth in sectors with the highest potential to learn from the West.

This pattern flips around 1890, a point at which Japan was becoming a major codifier. By 1895, the coefficient of British patent relevance is positive and significant at the one percent level. Although the coefficient remains positive and significant at this level throughout the rest of our sample period, the point estimates slowly decline (though not significantly), consistent with the conjecture that by 1910, Japan was shifting to Second Industrial Revolution technologies and becoming less reliant on older IR ones. Figure 11 shows the scatterplots for 1880, 1890, 1900, and 1910 to show that outliers are not driving these results. The timing of this effect is hard to explain with conventional stories. We do not detect a significant impact of BPR on exports until 37 years after Japan opened to trade and 27 years after the Meiji Restoration. Neither of these stories can explain this basic pattern of Japanese industrialization—namely, why Japan’s export composition shifted away from sectors that benefited most from technological progress before Japan became technically literate, and then shifted back towards them after.

²⁷Appendix Table A.4 reports the estimated coefficients from the same specifications.

Figure 11: Japanese Export Growth and BPR by Decade, 1880-1910



Note: These graphs plot the annualized growth rate between 1875 and year X against British Patent Relevance.

6 Robustness

Alternative Measures of Patent Relevance One possible concern about our results is that British patents issued between 1780 and 1852 may not accurately capture the set of codifiable technologies Japan and other periphery economies were interested in adopting during the sample period. While our baseline choice is justified by the technology adoption lags literature and the historical record for Japan, here we consider the robustness of our results to using patents that capture the most novel technologies as of 1880, and those from a different country at the technology frontier by the late 19th century. Specifically, we construct similar measures for British patents issued during 1853-1879, and for U.S. patents issued 1836-1879.

We explore how our choice of which sample of patents to use affects our results in Table 3. Column 1 is identical to column 1 in Table 2, and we report it again for reference. Next, in column 2, we show that our results are very similar if we use the full text of British patents 1853-1879. Column 3 repeats the exercise, first summarizing each patent using a generative AI model so that the summaries are similar in length to the British patent synopses used for 1780-1852; the results are almost unchanged.²⁸ Finally, columns 4-5 show that the results are also very similar if we use early (1836-1860) or later (1861-1879) US patent text to construct the cosine similarity measure.²⁹ Note that while using later British patents, as well as U.S. patents, does not significantly affect our coefficient of interest, it does lower the R^2 , suggesting that these innovations have less explanatory power for understanding the evolution of Japanese export growth. This is consistent with the

²⁸Appendix I.5 contains details of how the patent text was summarized.

²⁹Patent reforms in both Britain and the U.S. make it impossible to pool patents within a country for the full period we wish to consider. Specifically, we do not pool the entire corpus of British patents 1780-1879 because of a patent reform in 1852 that substantially decreased the cost of filing patents, and we do not pool U.S. patents 1836 (the first year they are available) - 1879 because of a patent reform in 1861. Appendix I.5 contains further information.

Table 3: Annualized Export Growth and Different Patent Relevance Measures

	Export Growth				
	(1)	(2)	(3)	(4)	(5)
BPR (1780-1852) $\times$ Japan	0.121*** (0.033)				
BPR (1853-1879) $\times$ Japan		0.121*** (0.036)			
BPR (Summarized, 1853-1879) $\times$ Japan			0.116*** (0.036)		
USPR (1836-1860) $\times$ Japan				0.111*** (0.036)	
USPR (1861-1879) $\times$ Japan					0.115*** (0.038)
Observations	71	71	71	71	71
R^2	0.113	0.082	0.080	0.063	0.068
Country fixed effects	✓	✓	✓	✓	✓
Sample	Japan	Japan	Japan	Japan	Japan

Note: The dependent variable, “Export Growth,” is the annualized export growth rate for a Japanese industry k between {1880,1885} and {1905,1910}. BPR stands for “British Patent Relevance” and captures how relevant British patents are to the vocabulary used in the manuals of industry k . BPR is standardized to have a mean of 0 and a standard deviation of 1. USPR stands for “United States Patent Relevance”, constructed in a similar way to BPR. The “Summarized” version used in Column (4) is explained in Appendix I. Robust standard errors are in parentheses: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

notion that our baseline BPR measure captures the set of technologies most important for Japanese export growth.

Productivity We have shown that patents affected the export behavior of codifying and non-codifying countries differently, but we have not shown that it mattered for the productivity of industries directly. For example, it is possible that BPR is correlated with the demand for Japanese exports, rather than the supply, and therefore our results may not accurately reflect movements in Japanese productivity. Fortunately, [Costinot et al. \(2012\)](#) build a multisector [Eaton and Kortum \(2002\)](#) model that provides a mapping from industry productivity into exports. In their setup, if one regresses a country’s bilateral industry exports on country-pair, importer-industry, and exporter-industry fixed effects, the coefficient on the exporter-industry fixed effect will be proportional to country-industry productivity. Following [Costinot et al. \(2012\)](#), we show in Appendix C.1 that these productivity estimates can be converted into measures of comparative advantage by netting out productivity shifts that affect all industries for a given exporter and industry productivity shifts that are common across all countries.

Using these productivity estimates, we show in Appendix C.3 that not only did Japan have exceptional manufacturing export growth between 1880 and 1910, but it also had exceptional national productivity growth, and this productivity growth was biased towards manufacturing sectors. Table 4 replicates Table 2 using productivity-based comparative advantage growth instead of export growth as the dependent variable (Figure A.8 shows the corresponding scatterplot for Japan). The results are qualitatively similar to what we found when using export growth as the

Table 4: Annualized Productivity Growth and British Patent Relevance

	(1)	(2)	(3)	Γ_{ik} (4)	(5)	(6)	(7)
BPR $\times$ Japan	0.012*** (0.004)	0.012*** (0.004)	0.012*** (0.004)	0.012*** (0.004)	0.012*** (0.004)	0.012*** (0.004)	0.012*** (0.004)
BPR $\times$ Not Japan		-0.000 (0.001)	-0.001 (0.001)	-0.001 (0.001)	-0.003 (0.002)		
BPR $\times$ English-Speaking			0.003 (0.002)				
BPR $\times$ French-Speaking				0.002 (0.002)			
BPR $\times$ Top-4 Codified					0.004** (0.002)		
BPR $\times$ High-Income						-0.003 (0.034)	-0.003 (0.034)
BPR $\times$ Medium-Income						0.050 (0.079)	0.079 (0.081)
BPR $\times$ Low-Income						-0.111 (0.083)	0.022 (0.096)
BPR $\times$ Asia							-0.277** (0.126)
Observations	56	1244	1244	1244	1244	1244	1244
R^2	0.074	0.010	0.011	0.011	0.013	0.012	0.016
Country fixed effects	✓	✓	✓	✓	✓	✓	✓
Sample	Japan	All	All	All	All	All	All

Note: The dependent variable is the annualized growth rate in comparative advantage for a region i 's industry k between {1880,1885} and {1905,1910}. "British Patent Relevance" is a variable that captures the extent to which the synopses of British patents are relevant to industry k . Japan dummy equals one if the region is Japan and zero otherwise. Not Japan is analogously defined. "Top-4 Codified" is a dummy for countries that speak one of the 4 most codified languages: French, English, German, and Italian. {High, Medium, Low}-Income are dummies are one when a region is in the top third of the income distribution (High), middle third (Medium), or bottom third (Low) according to the Maddison per capita GDP data; we set these dummies to 0 for Japan. The Asia dummy equals one if the region is in Asia and 0 if it is Japan or not in Asia. Robust standard errors are in parentheses: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

dependent variable. We find that BPR led to greater growth in comparative advantage in Japan and to deteriorations in comparative advantage in non-codifying countries. Between 1880 and 1910, we estimate that a Japanese industry with a BPR score one standard deviation higher than another experienced productivity growth that was 1.2 percentage points higher per year. Countries that codified also experienced significantly faster growth in comparative advantage in industries with

higher BPR, although the point estimates for codification in English and French are not precisely estimated. In other words, the results are qualitatively the same as those we obtained for export growth.

Controlling for Additional Confounders We also tested the robustness of our results by checking whether they could be driven by correlations between BPR and colonization and industry steam intensity. In Appendix Table A.5, we control for whether the region was a British colony (as opposed to being a plurality English-speaking country), but the coefficient is not significant. An alternative confounder is that BPR may be correlated with an industry’s steam-energy intensity, and our regressions are driven by Japan being a late adopter of steam power, which caused it to grow relatively quickly in steam-intensive sectors. We measure industries’ steam-power intensity using French data from the 1860s, defined as the amount of steam power used in an industry divided by the wage bill (details of the calculation can be found in Appendix H.6). Table A.5 shows that controlling for steam power does not affect our results.³⁰

Sample Selection Issues Appendix Table A.6 drops non-manufacturing sectors to show that the impact of BPR on Japanese export and productivity growth rates did not arise simply because of differences in manufacturing export growth relative to non-manufacturing export growth rates. We also demonstrate that our results for Japan are not driven by Japanese exports to any particular geographic region in Appendix Table A.7. Notably, our results hold excluding Asian destination markets which were the primary markets served by Japan (Meissner and Tang, 2018). Similarly, our results are not driven by individual high-growth sectors like textiles or iron and fabricated metal products (Table A.8). Together, these results indicate that broad-based changes were underway in Japan. These patterns are even visible within the manufacturing sector and are detectable even if we drop Japan’s major export destination markets or its major export products.

7 External Validity

Our paper began with the observation that there are only four types of high-income countries: English-speaking countries, countries close to England, resource-abundant countries, and Japan and its former colonies. While it is beyond the scope of this paper to assess the external validity of our findings by conducting a similar analysis of codification on other countries, we can ask whether the Meiji model of codification was influential beyond Japan, and whether it could have had similar effects in other contexts.

In terms of its influence, there are two countries where we have direct evidence of the Meiji model of technology absorption being studied and transplanted: South Korea, under the Japonophile President Park Chung Hee, and China, under Premier Zhou Enlai (China’s second-highest government official). Both men studied in Japan in their youth, and each was inspired by the Meiji economic model. Kohli (1994) writes that Park, who graduated fifth in his class from the prestigious Imperial Japanese Army Academy (during the period when Korea was a Japanese colony), was “fascinated by the ‘Meiji model,’ and bent on steering Korea along the Japanese path to modernity.” Similarly, Zhou had spent two years studying economic development in Japan, and his views on technology policy were similar to those of Sakuma (presented at the beginning of this article), close to one hundred years earlier:

³⁰Steam-engines were used outside of manufacturing too, where British Patent Relevance tends to be low. For example, the mining of coal and other natural resources is steam-intensive, but these industries do not have a high BPR_k s. This likely explains why our results are robust to the inclusion of a measure of steam-intensity.

Doing science is like fighting a war... How can you fight this war? The foundation of our country's scientific and technological information work is very weak. The main task of intelligence work is to quickly establish institutions, train experts in intelligence work, comprehensively and on a timely basis collect, research and report on the development and new achievements of science and technology at home and abroad, especially in advanced scientific countries, so that national scientific work can understand these developments and achievements promptly. The specific method is to prepare for the establishment of specialized institutions, organize forces, engage in extracting papers from scientific and technological journals around the world, and compile, print, and publish. (Hannas and Chang, 2021, pp. 9-10)

Upon coming to power, each leader implemented technology policies which bore clear resemblance to the Meiji technology policies studied in this paper. For example, it is commonly argued that "the regime of Park Chung Hee, which lasted from 1961 to 1979, changed the course of modern South Korean science and technology." (Kim, 2011). Starting in 1962, Park developed a five-year technology plan based on the idea that "the promotion of science and technology is the most pressing issue for South Korea... Neither economic growth nor modernization can be achieved without progress in science and technology." [Park as quoted in Kim (2011)]. One of the cornerstones of his policy was the establishment of the Korea Institute of Science and Technology (KIST), which had a budget exceeding total university expenditures on science and engineering. The first director of KIST explained its mission: "At that time, no such institutes had researched the manufacturing technologies that companies demanded... In other words, there should be an intermediary unit for selecting, introducing, acquiring, and applying technologies." [Hyung Sup Choi as quoted in Thang (2018)]

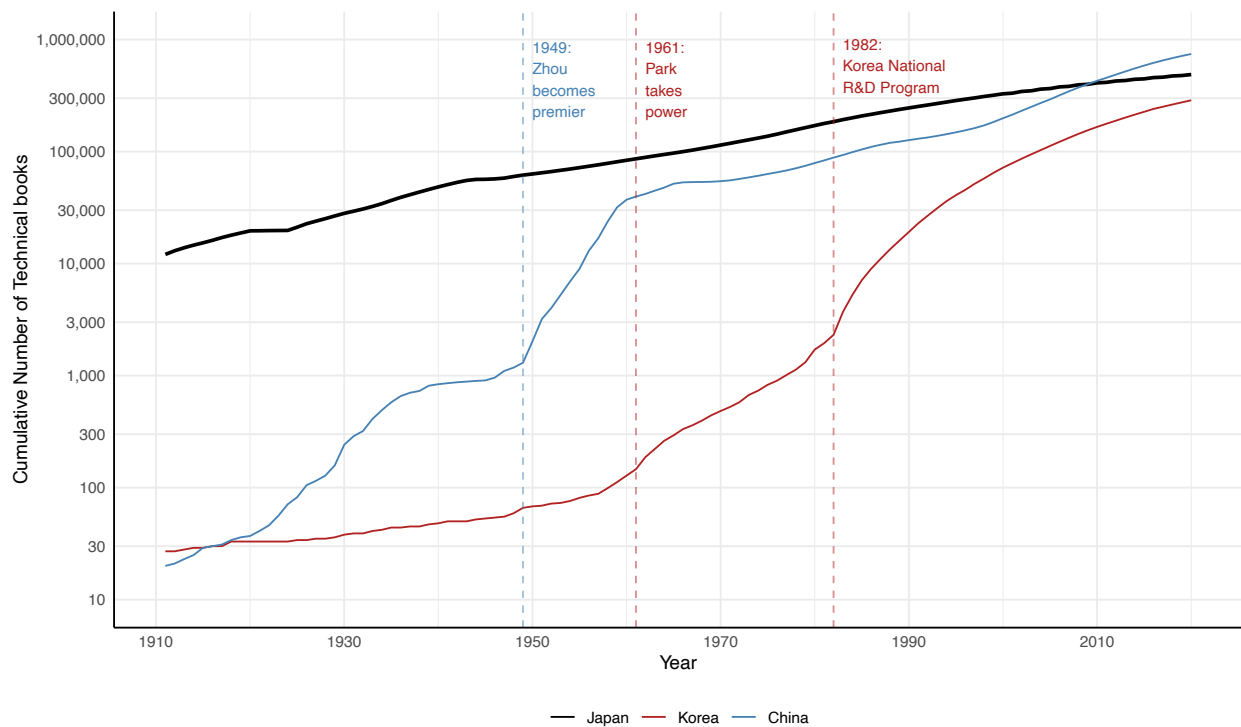
Fulfilling this mission involved an enormous expansion in the number of researchers in government research institutes and universities. Between 1965 and 1970, the number of researchers in government institutes rose from 2,135 to 5,628, and the number of university researchers rose from 352 to 2,011. After his assassination in 1979, Park's policy was supplemented in 1982 by the National R&D Project, which created government research institutes aimed at improving the level of domestic technology. As a result, the number of researchers in government research institutes rose from 4,598 to 7,542 between 1980 and 1985 and then doubled over the next decade (Chung, 2020).

Similarly, China's approach to technology adoption in the 1950s closely mirrored Meiji Japan's, with the Soviet Union playing the role of Britain. For example, Mengzhi (1999) writes that "after the foundation of the People's Republic of China, the government took emergency measures to train people with ability in foreign languages, especially Russian, to meet the needs of large-scale economic production... A large number of translated Russian textbooks were published to meet the requirements of various specialties." [p. 189]

We examine the impact of these policies on the publishing of technical books by scraping the national libraries of China, Japan and Korea.³¹ In Figure 12, we plot the cumulative number of technical books available in the vernacular for each country. In 1950, Japan had about 70,000 technical books, while China had about 1,000, and Korea had fewer than 100. In China, the publication of technical books rose sharply the moment Premier Zhou Enlai became Premier, and by the early 1960s, there were over 30,000 technical books. The growth in technical books is also significant in Korea, and there is a clear acceleration in growth rates in both 1961, when President Park came to power, and 1982, when the National R&D plan was adopted.

³¹We start in 1911 because Maddison data on real per capita income in Korea in earlier years is based on

Figure 12: Cumulative Number of Technical Books in Japan, Korea, and China



Note: Codified technical knowledge for each year refers to all technical books written in Japanese in the NDL catalog, Korean in the National Library of Korea, or Chinese in Shanghai's Library. The y-axis is on a log scale.

Figure 13 shows per capita income growth for these three economies. We highlight two points. First, GDP per capita in South Korea clearly rises when Park comes to power and fosters codification efforts. While we do not interpret this relationship causally, it is at least plausible that codification played a role in the take-off of economic growth in Korea.³² Second, Figure 13 reveals that codification in China failed to deliver long-run economic growth: by 1961, Chinese income was barely above where it had been in 1950. Moreover, despite robust growth in codification from 1960 onwards, Chinese growth rates did not pick up until after 1976.

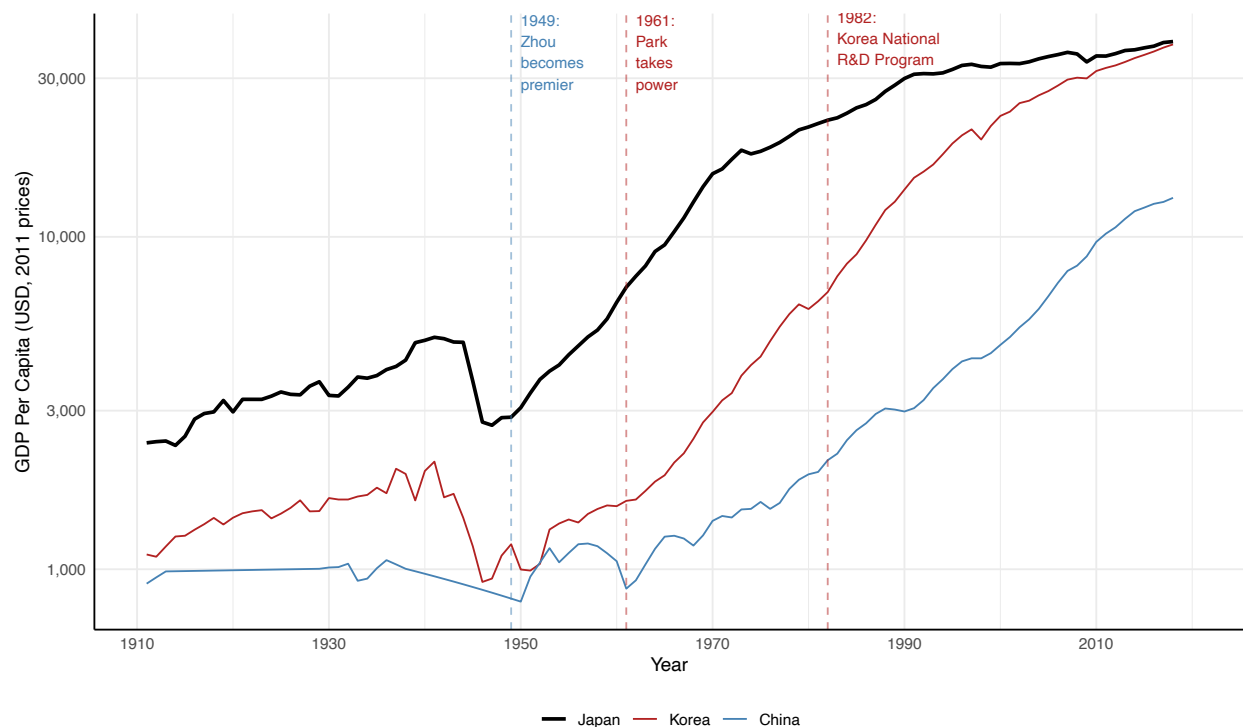
Mao's disastrous policies, such as the Great Leap Forward (1958-1962) and the Cultural Revolution (1966-1976), are likely the culprits behind why the Chinese people failed to benefit from their technical knowledge. Once the Cultural Revolution ended, it is plausible that codification and the gradual introduction of market forces into the economy led to a sustained rise in growth rates that persisted for 40 years.³³ In other words, China is the exception that proves the rule—its experience is consistent with our contention that codification is a necessary but not sufficient condition for development: totalitarianism can eliminate the benefits of codification.

extrapolating backwards.

³²Recent work by Lane (2025) shows evidence for the growth-enhancing effects of other *sectoral* industrial policies adopted in Korea at this time.

³³In related work, Giorcelli and Li (2021) find evidence that firms which directly received Soviet technical support during this period outperformed firms which did not.

Figure 13: Real GDP per capita for Japan, Korea, and China



Source: [Maddison Project Database \(2020\)](#). The y-axis is on a log scale.

The implication we take from this discussion is that the Meiji technology policies studied in this paper have been without a doubt influential beyond the borders of Japan. In fact, the discussion above shows that these policies were studied and adopted by two other East-Asia “miracle economies” (though China’s economic miracle came much later than the initial state-led codification effort under Zhou Enlai). While there has been much debate and controversy surrounding the role of more standard *sectoral* industrial policies for these economies’ growth miracles (see [Juhász et al. \(2024\)](#) for a recent discussion), our analysis suggests that the literature may have overlooked a different form of industrial policy adopted in a number of these countries: the public provision of technical knowledge in the vernacular. A fruitful direction for future research would be to estimate the causal effect of these technology policies in other contexts.

Notwithstanding the eventual influence of the Meiji model of codification, one may also wonder how our findings apply to other countries for the period examined in this paper. In Appendix D, we discuss how our findings inform the experience of two other late-industrializing economies: British India and Late Imperial Russia.

8 Conclusion

This paper presents evidence supporting the argument that the public provision of technical knowledge in the vernacular reduced an important friction that impeded the absorption of Western technology in Meiji Japan. Our results reveal an empirical pattern unique to Japan and other codifiers: industries that stood to benefit more from Western technology experienced faster growth in exports and productivity in relevant sectors. The cross-region evidence and the timing of when

technical knowledge became predictive of industry growth in Japan provide a strong case for a causal interpretation of codification on Japanese export and productivity growth. By making technical knowledge widely available in the vernacular, the Meiji government relaxed a critical bottleneck for industrialization. This suggests that regions hoping to emulate European industrialization in the nineteenth century, particularly those linguistically or geographically distant from Western Europe, needed to provide complex public goods, such as access to technical knowledge, to emulate Britain successfully. Any alternative explanation of Japanese export and productivity growth must account for both its distinctive pattern across regions and its timing in Japan.

There is also suggestive evidence that these forces mattered for aggregate growth in Japan and other Asian nations. Both Japan and Korea experienced sustained increases in their average per capita growth rates only after embarking on significant codification efforts. However, our results also suggest that these public goods were unlikely to be sufficient in and of themselves to foster modern industrial development. China embarked on a similar codification strategy in 1949, but it did not experience sustained fast growth until after it abandoned Maoist economic policies. This buttresses our contention that codification may have been necessary but not sufficient for development.

The obvious question is why the Japanese government was unique among peripheral regions in first providing these public goods. Our reading of the historical record suggests that it was the severe, existential threat to the Japanese regime caused by the arrival of Western powers that aligned the elite in support of a strategy of aggressive defensive modernization.³⁴ A central part of this effort, as we have shown, was the absorption of Western science and technology. Historians argue that one important advantage Japan had was that its contact with the West happened late, meaning that it could observe and learn from what happened to China. Senior members of the shogunate correctly anticipated that Japan would be the next target of Western imperialism, and efforts were underway even prior to the Meiji Revolution to learn from the West. Importantly, however, Japan did not need to discover the policy tools itself. State support of technology absorption, particularly the translation of technical books, was a common strategy for regions hoping to emulate Britain. This has been observed from Bourbon France in the late eighteenth century to the Self-Strengthening Movement in China in the nineteenth century (Juhasz and Steinwender, 2024). Meiji Japan thus took the state-led technology adoption playbook developed elsewhere and deployed it at an unprecedented scale.

³⁴See Koyama et al. (2018) for a geographic explanation for why Chinese and Japanese responses to the West in the nineteenth century differed.

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