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A TALE OF TWO SICS: JAPANESE AND AMERICAN INDUSTRIALIZATION IN HISTORICAL PERSPECTIVE

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A Tale of Two SICs: Japanese and American Industrialization in Historical Perspective

Abstract

Late developing countries are able to adopt best practice technologies pioneered abroad, allowing more rapid convergence toward leading economies. Meiji Japan (1868-1912) is considered a successful example of industrial convergence, but much of the evidence relies on national aggregates or selected industries. Using historical industry data, this paper examines whether Japan adopted new technologies faster compared to the United States. Contrary to conventional wisdom, duration analysis indicates that new sectors did not appear relatively sooner in Japan; however, they did grow to economic significance faster. Higher firm capitalization and capital intensity are also associated with earlier entry for Japanese sectors.

Keywords: convergence, industry classification, survival analysis, technology adoption and diffusion

JEL codes: N11, N15, O14, O33

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Between 1870 and 1900, the United States saw a three-fold increase in the value-added of manufacturing, with its share of national output rising four per cent over the period to just under a fifth of total income (United States Bureau of the Census 1975). While this rapid expansion of American industry laid the groundwork to the country's economic leadership in the twentieth century, no less remarkable was the catch up of other late developing countries, particularly Japan. Starting from a much smaller base, Japanese industry also grew apace, with manufacturing's share of national income increasing four per cent between 1885 and 1900, and another three per cent the following decade to reach 18.5 per cent in 1910 (Japan Statistical Agency 2007). In effect, what took the United States three decades was achieved by Japan in half the time, with even more dramatic catch-up compared to earlier industrializers like the United Kingdom.¹

As with other late developing countries, Japan had the opportunity to accelerate its development by adopting technologies at their current best practice, also known as technological convergence or leapfrogging. This process, identified with Alexander Gerschenkron's (1962) theory of economic backwardness, allows for potential savings in time and resources for the economy as a whole.² While many small-scale, traditional industries continued to be important over this period, some of these (e.g., silk reeling, food processing) and novel sectors (e.g., chemicals, railroads) benefitted from international market access and mechanization. Furthermore, policymakers are able to target industries that may have a relative comparative advantage and for entrepreneurs to compete with established foreign producers in local and possibly international markets. This appears to have been the case for leading Japanese sectors like railroads and cotton textiles that used state-of-the-art equipment and production techniques (Tang 2014; Saxonhouse 1974). Less is clear is whether the country's path to industrialization can generally be described as asynchronous for the economy as a whole or if adoption was ad hoc and specific to certain industries.

¹ "In England the factory system evolved over two centuries or more; in Japan it was established in fifty years, or even less" (Lockwood 1954, p. 187).

² "[T]he higher the degree of backwardness, the more discontinuous the development is likely to be" (Gerschenkron 1962, p. 45). Some constraints to acquiring frontier technologies include the size of industrial investments, available production inputs, and prevailing institutional frameworks may limit the scope of non-linear adoption and economic development.

While numerous studies have examined economic convergence between leaders and laggards, few examine the actual timing or dimensions of technological catch-up. Do increased labour productivity or the number of steam engines used in a given sector constitute sufficient statistics to assess industrial advancement or economic policies? How can different types of technologies and sectors be measured and compared without loss of generality? These issues, difficult by themselves within a single economy, are magnified when making international comparisons that cross time and space. Japan's industrial development in the Meiji Period (1868-1912), however, provides a unique context to analyse the dynamics of technology adoption due to its relative isolation prior to its integration into the world economy and the observed introduction of foreign technologies thereafter.

This paper takes a different approach to measuring the relative speed of technology adoption and diffusion compared to earlier scholarship, and does so using official industrial statistics from Japan and the United States in the late nineteenth century. For both countries, this period of time coincided with major waves of industrial development, and in the case of Japan, its initial industrial transition. That said, given their significant differences in factor endowments, institutions, and other economic features, making cross-country comparisons can be problematic. As a consequence, I make two important simplifying assumptions: that individual industries embody specific technologies, which may overlap but not in their entirety; and that the chronology of an industry's appearance and growth approximates the embodied technologies' adoption and diffusion, respectively.

Unlike data measuring different types of technology, which are not consistently recorded across countries or can be easily compared and aggregated across sectors, data for industries are more readily available. These official series, which include figures on establishments and industry capitalization, allow one to identify when sectors appeared in both countries and grew in economic importance and thus measure relative technological convergence. To make comparison, I standardize the classification of the two countries' industries to a single system based on the 1987 U.S. Standard Industrial Classification (SIC), and any relative differences may in turn demonstrate the extent to which Japan engaged in technological leapfrogging relative to a recognized

industrial leader (Statistics Bureau of Japan 2009; United States Bureau of Labor Statistics 2014).³

Estimates from duration model analysis show substantial differences in the respective industrial development of the two countries in the second half of the nineteenth century. Consistent with Gerschenkronian backwardness, per capita income levels were inversely correlated with the speed of adoption in general for both Japan and the United States; in other words, both countries adopted new technologies more rapidly when they were at an earlier stage of development. However, benchmarked against the United States, new manufacturing sectors do not appear in Japan relatively earlier and in some cases emerge later. In both countries, but especially true for Japan, industries with larger firms are associated with faster introduction. Furthermore, unlike in the United States, a lower share of capital among related sectors and higher capital intensity both appear to speed up technology adoption.

In contrast, for industries that became economically significant, defined as those attaining at least half a per cent of total manufacturing capital stock, Japanese industries passed the threshold more quickly than those in the U.S. This result obtains even though both per capita income levels and firm size become directly correlated with economic significance (i.e., richer countries pass the capital share threshold sooner). Results for both new industry entry and industry significance are robust to different specifications, although higher capital thresholds weaken the significance of faster Japanese industrialization.

As a whole, these results add to the newer body of research that questions whether Japanese industrialization was based simply on accelerated adoption and diffusion of foreign technologies. In particular, by controlling for industry characteristics and differentiating between sector appearance and their rise to economic importance, the two phenomena of adoption and diffusion exhibit significant differences. Relative to the United States, new technologies in Japan were adopted more slowly, but once introduced spread more quickly through the economy. One possible explanation may be that the industry classification system is too coarse to capture small-scale innovation and entrepreneurship, and there is evidence that individuals and

³ Strictly speaking, neither country had a standardized industrial classification system before the 1930s, with the United States issuing its first classification system in 1941 while Japan did the same in 1949.

independent firms were more innovative than the largest ones better captured in the official statistics (Nicholas 2011; Tang 2011). At the same time, given the relative concentration of firms in Japanese industries, larger firms may have been able to standardize application of new production techniques more effectively, which is supported by more recent studies on managerial practices (Braguinsky et al 2015). These interpretations, and the data and analysis underlying them, are discussed in more detail in the following sections.

HISTORICAL CONTEXT AND LITERATURE REVIEW

In his theory of late development, Gerschenkron identified Germany and Russia as having industrialized with unusual rapidity in the second half of the nineteenth century. Writing that "[i]ndustrialization always seemed the more promising the greater the backlog of technological innovations which the backward country could take over from the more advanced country" (Gerschenkron 1962, p. 8), he credits their achievement to the ability to adopt pre-existing technologies developed by industrial pioneers like the United Kingdom and United States. This observation has been the subject of an extensive literature on economic convergence that measures differences in national income, productivity, capitalization, and institutions (Abramovitz 1986; Baumol 1986; Benetrix et al 2015; Delong 1988; Rodrik 2013; Sokoloff and Engerman 2000).

Until the mid nineteenth century, Japan was an economy organized along feudal lines and engaged primarily in traditional agricultural production (Ohkawa and Rosovsky 1973). This changed markedly toward the end of the century, following the country's (forced) opening to the international economy. In 1868, the year of the Meiji Restoration, two-thirds of gross national output came from primary sector production; by 1905, this share fell to under forty per cent, similar to the proportion coming from a swiftly growing textile manufacturing industry (ibid, p. 15). Even with these gains, Japan remained in absolute measures significantly behind industrial leaders like the United States, but the relative disparity had narrowed. Table 1 presents some measures of economic activity for both Japan and the United States.

[Table 1]

Similar to the experiences of other successful late developing countries, Japan's modernization is attributed to the adoption of foreign technologies, increased capital

accumulation, and higher levels of productivity, although the analyses typically rely on national aggregates or are not empirically verified.⁴ A visible example of foreign technology adoption was the introduction of the railroad in the early 1870s, which expanded rapidly in the next three decades and linked population areas, provided access to natural resources, and increased firm scale (Tang 2014).⁵ Recent scholarship confirms Japan's precocity among countries in the industrial periphery, with growth rates exceeding the leading economies of the United States, United Kingdom, and Germany starting in the 1890s and continuing for most of the twentieth century (Benetrix et al 2015).⁶

Notwithstanding the insight gained from estimating industrial growth rates and aggregate productivity levels, what remain unclear are the specific mechanisms underlying economic convergence as well as which industries are affected and how sectoral differences can be measured.⁷ In the case of Meiji Japan, besides transportation infrastructure, numerous studies have identified other contributing factors to its industrial take-off, such as public investment, entrepreneurial capital, and financial market access, and management practices (Braguinsky et al 2015; Morck and Nakamura 2007; Rousseau 1999; Tang 2011, 2013).⁸ Technological change may also have benefitted from a Japanese marketplace that rewarded independent innovators, who took advantage of (and were rewarded by) the country's newly established patent system to introduce new technologies (Nicholas 2011). Besides their introduction, as

⁴ Other possible influences not directly related to technology adoption include Japan's high absorptive capacity due in part to its "well-functioning sociopolitical infrastructure" (Ohkawa and Rosovsky 1973, p. 39) and the economic consequences of market integration (Lockwood 1954, pp. 17-18).

⁵ Railroads were also heavily utilized in Japan's military victories against China (1895) and Russia (1905), which provided the country with its first colonial possessions, reparations, and international status. Military success also increased Japan's debt capacity and access to international capital markets (Sussman and Yafeh 2000).

⁶ While Japan was the first Asian country to reach the five percent threshold of industrial growth rates, it initially lagged behind countries in the European periphery and Latin America.

⁷ Abramovitz (1986, p. 395) states that "[p]roductivity levels...were erratic indicators of gaps between existing and best-practice technology."

⁸ Tang (2011) identifies the large, family-owned zaibatsu conglomerates as instrumental in introducing many new technologies to the economy, which may be due to the firms' increased risk capacity and lower capital costs from internal financing. Braguinsky et al (2015) find that better managed cotton spinning firms increased profitability in newly acquired facilities through lower inventories and increased capacity utilization.

crucial was the diffusion of best practices, with sectors like cotton spinning directly benefitting from the use of American ring spindles (replacing British mule spindles), which took advantage of the country's abundant labour and consumer demand for lower quality and cheaper textiles (Saxonhouse 1974).

While there is substantial variation across countries in how quickly they adopt technologies, successful latecomers to industrialization like the East Asian tiger economies appear to have caught up with technological leaders by reducing the adoption lag in a subset of technologies (Comin and Hobijn 2010). However, it is uncertain whether the impact of innovations from individual sectors generalizes to the economy as a whole or how different technologies and their economic significance can be compared to each other.⁹ Innovation is typically identified at a micro-level (e.g., patents, products) or backed out as a residual in macroeconomic production functions (Mokyr 1990; Fukao et al 2015).¹⁰ At the industry level, there is ambiguity as to what constitutes technological progress (as opposed to capital utilization and labour productivity), and this is further complicated by data availability and comparative consistency between sectors. In more practical terms for analysis, it may be infeasible both to make an exhaustive inventory of all micro-inventions to estimate a national value or isolate the value of general purpose technologies that are used in multiple sectors or goods.

This paper addresses these measurement issues by assuming that industry classification itself is a useful gauge of technology differences, and the emergence and growth of different industries over time representing technological adoption and diffusion. This assumption has historical precedent both in economic analysis and in the construction of industrial classification systems, with Abramovitz (1986, p. 386) claiming that technology is embodied in the capital stock and the "technological age of the stock is, so to speak, the same as its chronological age." The United States Standard Industrial Classification (SIC) system itself is oriented around production techniques, which served the country's statistical agencies well until the nature of production

⁹ Gerschenkron (1962, pp. 42-43) suggests per capita output as a measure of backwardness as unsatisfactory given differences in the range of output and availability of price data. A notable example of consistent measurement and economic impact in technology adoption is Saxonhouse and Wright (2010), which tracks the diffusion of cotton spinning technology over fifty years across multiple countries.

¹⁰ Mokyr's distinguishes micro-innovations as being incremental improvements in productivity while macro-innovations relate to paradigm shifts.

shifted in the late twentieth century (United States Bureau of Economic Analysis 1994). Applied to the industrialization of Japan in the late nineteenth century, with the contemporaneous experience of the United States used as a reference, this framework allows one to test hypotheses regarding technological convergence. Some include whether new Japanese industries appeared relatively sooner compared to those in the U.S.; whether their emergence was affected by the scale of enterprises within those sectors and industry-level capital intensity; whether the existence of similar industries encouraged the introduction of new, but related technologies; and if there was a difference between appearance of an industry (i.e., adoption) and its growth to economic significance (i.e., diffusion).

DATA SOURCES

The data used in the analysis come from official records collected by the statistical agencies in the two countries, either in statistical yearbooks (Japan) or decennial economic censuses (United States). Specifically, data in the *Statistical Yearbook of the Japanese Empire* were compiled by the Prime Minister's Cabinet Statistics Bureau from different government agencies' records and occasionally from individual firms into annual reports between 1883 and 1936 (Japan Statistical Association 1962). The information included in these yearbooks covers all aspects of the Japanese economy and population and often at the prefecture and industry level, although not necessarily both. Industry statistics were progressively standardized during the 1880s and 1890s in terms of the amount of detail included and how sectors were classified, such as the reporting of manufacturing separate from sales starting in year 1885. Industry names also changed slightly to accommodate expansion or contraction of activities. For the Meiji Period, consistent series at the industry level are available from the mid 1880s for the number of establishments and the amount of paid-in capital, whereas data on employment, raw materials, and output are not comprehensive across sectors until the early 1900s.

In contrast, perhaps due to the relative enormity of the task and infrequency of data collection, American statistics tended to be more complete. Starting with the 1810 census, economic data collection took place along with population enumerations every decade until the turn of the century, when a permanent census office was established in

1902 (Boehme 1987; United States Bureau of the Census, various years).¹¹ The Permanent Census Act had provisions for economic statistics to be collected on a five-year basis starting in 1905.¹² While accuracy and information increased during the nineteenth century, such as including workers, raw materials, and equipment (1820) and adding sections on fishing, mining, and trade (1840), it was not until the second half of the century that consistent and detailed instructions were used in the enumerations (1850) and that trained specialists instead of U.S. marshals collected the data (1880).

These changes in coverage for both countries mean that reliable industrial data can be analysed only after 1885 for Japan and 1850 for the United States, and these are limited to a small number of series available for all manufacturing sectors, namely the number of establishments and capital value.¹³ Fortunately, the decades following these two starting points sufficiently span major periods of industrial development in both countries, as shown in Table 1.¹⁴ For Japan, the initial wave of sustained industrial activity occurred after the fiscal retrenchment of the early 1880s, when the government privatized many of its enterprises and its financial restructuring stabilized the currency and reduced inflation (Allen 1946, pp. 46-47). In the quarter century to 1910, the number of firms increased seven-fold while their nominal level of paid-in capital rose by a factor of twenty (Japan Statistical Association 1962).¹⁵

Meanwhile, the United States was undergoing significant structural change following its Civil War in 1861-65. The economy began to actively employ mass production techniques and to expand its manufacturing sector, which exceeded

¹¹ The 1810 census was the third to take place, and included for the first time questions on goods and manufactures. Atack and Bateman (1999) also describe changes in data collection and quality over time. Japanese statistical collection increased in sophistication as well, which may be due to greater institutional capacity acquired over time.

¹² The frequency of economic censuses also changed to biennial, then four-yearly enumerations before returning to a quinquennial basis; *ibid.*

¹³ Even these series are not exact mappings, with Japan reporting nominal paid-in capital value for industries while the United States giving the value of industries' fixed capital assets.

¹⁴ Table 1 omits the column containing statistics for the 1905 economic census, which are included in the regression analysis.

¹⁵ Official firm numbers may understate entrepreneurial activity such as that performed informally or sole proprietorships, with more accurate figures reported starting in the mid 1880s (Tang 2011). Financial figures are given in current U.S. dollars at market exchange rates for Japan, which are likely to be underestimates compared to those calculated using purchasing price parity (PPP).

agriculture in value in the 1880s and was the international leader by 1900 (Atack and Passell 1994, p. 457; Boehme 1987). The periods of analysis for both countries end in 1910, which coincides with the last years of the Meiji Period and Japan's first wave of industrialization. It also allows use of the last quinquennial American economic census prior to World War I, which further changed the composition and development of the two economies.

Comparing Japan's industrial development with that of the United States is complicated by the fact that neither country had a standardized industry classification (SIC) system until well into the twentieth century. To ensure consistent comparison over time and between countries, industries from the Japanese yearbooks and American censuses are coded retroactively using the 1987 United States SIC system at the three-digit level (United States Office of Management and Budget 1987).¹⁶ This coding reduces the number of industries listed in the historical records on average by a factor of two. For the United States, the number of SIC3 industries was fairly unchanged throughout the late nineteenth century, around one hundred, while in Japan the number steadily increased, trebling in twenty-five years. By 1910, Japan had nearly two-thirds the number of SIC3 industries as the U.S., compared to less than one-fifth in 1885. This absolute growth in Japanese SIC3 industries is also reflected in the number of completely new sectors, with twenty appearing within five years after 1885 and another nineteen in the following ten years. A similar increase of industrial diversification occurred in the United States two decades earlier, when nineteen new industries appeared between the 1850 and 1860 censuses, and another thirteen in the next two decades.¹⁷

In addition to the official records used to construct these industrial series, a few other sources of statistics are used. For Japan, these include national income and population figures from the *Historical Statistics of Japan* collection and industry output values from the *Estimates of Long-Term Economic Statistics*; for the United States,

¹⁶ Atack and Bateman (1999) also use three-digit 1987 SIC codes in their analysis of U.S. Census of Manufacturing extracts for the 1850, 1860, 1870, and 1880 enumerations.

¹⁷ The data appendix lists new industries in both countries by three-digit SIC and time of appearance. Note that the timing of industry appearance does not preclude earlier existence in the economy (e.g., textile dyeing and finishing), but reflects the shift toward modern production methods; scale sufficient to merit itemized classification; and government interest in recording the activity; see the concluding section and Tang (2011) for a discussion.

historical estimates of national income and population come from *Measuring Worth* (Japan Statistical Association 2007; Shinohara 1972; Williamson 2015). It should be noted that the two countries differ in the methodology used to calculate national income, with the United States measuring it as gross domestic product while for Japan it was typically gross national expenditure.¹⁸ Furthermore, Japanese industry output values are aggregated at a much higher level (two-digit SIC) than those for the U.S. While this does not pose a technical problem for the analytical model since the output values series are used to construct average capital intensity ratios (capital value to output value), it does mean that figures for Japan will be less precise than the equivalent American ratios. All income and output values are in current U.S. dollars, with the Japanese figures converted from yen using prevailing market exchange rates averaged over the given year.

EMPIRICAL METHODOLOGY

To test the hypothesis that Japan adopted technologies faster than advanced economies like the United States, and thus enabling it to converge toward industrial leaders, this paper uses a duration analysis model to compare the relative timing of industry development in the two countries. Duration analysis models, also known as survival analysis models, measure the hazard rate (risk) of an event occurrence, like death or unemployment (Cleves et al 2008).¹⁹ In terms of this paper, the analysis estimates the expected time to when a new industry will appear in an economy based on a parametric model conditional on covariates that may influence the occurrence like per capita income. One of the advantages to using duration analysis instead of other regression models is that censored subjects (e.g., industries that do not pass the capital

¹⁸ Similarly, the *Estimates of Long-Term Economic Statistics* volume edited by Ohkawa et al (1974) report gross national expenditure. GDP measures are available for Japan, but post-date the earliest available industrial series (Japan Statistical Association 2007). There are efforts to update the historical estimates of Japanese output, but currently are unavailable at an annual or quinquennial basis; for example, Fukao et al (2015) estimate production levels using prefectural data for the pre-World War One years of 1874, 1890, and 1909.

¹⁹ There are a number of duration model types (e.g., parametric, semiparametric) and probability distributions (e.g., exponential, Weibull), the selection of which depends on the outcome of interest (e.g., duration time, relative hazard ratios) and observed or expected behavior over time, respectively.

threshold) remain in the analysis and thus improve the precision of the estimated coefficients.

Before continuing, it may be reasonable to consider whether duration analysis is appropriate to model industry emergence in both countries for the periods in question. Figure 1 plots the appearance of new industries (vertical axis) over time as given in the data, and shows comparable trends for the United States and Japan, albeit separated by nearly three decades. The Japanese trend is also more compressed in timing, which corresponds with its faster industrial growth rates relative to the United States. In both countries, new industries appear mostly in the first third of their respective periods of analysis, with a noticeable decline in technology adoption thereafter.

[Figure 1]

Figure 2 plots the two countries' curves as estimated probabilities of new industry appearance in a given year using the Kaplan-Meier survival function. The interpretation is that the likelihood (vertical axis) of new industry appearance is high early in the period of analysis for each country, with subsequent appearances less likely to occur over time. Here the similarity between the two countries' curves is even more striking, with all estimated probabilities statistically significant at least to the ten per cent level. Log-rank tests of equality between the two countries' survival functions also fail to be rejected at that level.

[Figure 2]

Given the differences in capital investment and economic development over time and between countries, it may be more informative to include additional variables that may influence the timing of industry appearance. Assuming a conditional probability of industry appearance that is constant over time (i.e., a Poisson or exponential distribution), which is consistent with the observed pattern of appearance shown in Figure 1, the basic functional form of the model is:

$$\log(t) = X_i\beta_1 + X_{ij}\beta_2 + z, \text{ where}$$

t = time to industry appearance

X_i = country-level variables indexed by i

(e.g., per capita income, Japan indicator variable)

X_{ij} = control variables indexed by country i and industry j

(e.g., average firm capital level, interaction variables)

z = error term

New industries are identified using the earliest available data: for Japan, these include industries starting in 1885, and for the United States, those in 1850. Using these sets of sectors as benchmarks for each country, any sectors appearing in successive years until 1910 are considered new, with the corresponding duration in between measured as an outcome variable t . The group of industries from the reference years, which are considered left-truncated, are omitted from the analysis.²⁰

The model tests whether time-to-appearance is associated with the following economy and industry level differences: a) income per capita, as a proxy for relative backwardness; b) a Japan indicator variable, to identify differences between the two countries; c) the average level of firm capital in each country, calculated by dividing an industry's capital value by its number of enterprises, as a measure of firm scale; d) the share of capital invested in similar sectors (i.e., three-digit SIC industries within the same two-digit industry group) out of total capital invested across manufacturing sectors in country i , to account for relative innovativeness; e) industry capital intensity in country i , which is the value of capital divided by the value of output; and f) interactions between the Japan indicator and industry level variables.²¹

Since the impact of industrialization is felt more in its sustained growth over time as opposed to a possibly short-lived market appearance, separate regressions are run using as the dependent variable the duration until an industry attains economic significance, defined as having at least half a per cent of the country's total manufacturing capital.²² This dependent variable allows inclusion of industries that appear in the data series, but do not receive sufficient capital investment, thus

²⁰ Left-truncation differs from left-censorship in that the latter includes industries that have not yet experienced a threshold event, but their existence precedes their appearance in the data. This difference is meaningful only in the duration analysis of economic significance as new industries appearing in the data have no prior existence.

²¹ A similar method of assessing industry innovativeness is used in Tang (2011).

²² Given approximately two hundred possible three-digit SIC industries, the half per cent threshold would approximate a uniform distribution of invested capital for each industry (i.e., each industry of equal importance). Since industries varied considerably in age and capital investment, it is expected that this threshold is a reasonable metric to measure absolute growth and technological diffusion. Separate robustness checks using the higher threshold of one percent total manufacturing capital stock are also performed and presented in the following section.

improving the estimates of the coefficients as well as increasing the overlap of industries between the two countries.

One issue with matching the industrial data between Japan and the United States is that those for the latter were collected every ten years before 1900, whereas the Japanese data are annual. Thus, dating the appearance of new industries and when industries attain economic significance in America is less precise (also known as interval censorship). Consequently, this may bias the results in favour of finding technological convergence for Japan since the dependent variables measure the duration until appearance or diffusion. To mitigate this bias, both countries' data are coded as five-year intervals (which also coincide with the post-1900 U.S. enumerations), and imputing event occurrence dates in a shorter span of time for U.S. sectors. For example, in measuring the time for an American industry to pass the half per cent threshold of total capital stock, if the sector has a capital share of 0.1 per cent in 1860 and 2 per cent in 1870, instead of dating the occurrence as passing the threshold in 1870, it is coded as 1865 based on the arithmetic average between the two enumerations. Attendant covariates like related industry capital share and capital intensity are similarly imputed. To match the level of imprecision in the American data, Japan industries are recoded also in five-year periods, which means they may appear up to four years later (e.g., an industry appearing in 1891 coded as 1895) and would use the later date's industry- and economy-level values in the covariates.

REGRESSION RESULTS

Regression results from the parametric duration model indicate that while lower per capita income is associated with faster technology adoption, new industries did not appear relatively earlier in Japan compared to the United States. As shown in Table 2, the coefficient on per capita income (row 1) is positive, which indicates increased duration until industry appearance, and usually statistically significant. This is consistent with developing countries converging toward technological leaders, with new manufacturing sectors appearing earlier presumably due to a technological backlog from which to establish industries. However, the Japan indicator variable (row 2) is also positive and despite most of its interactions with industry covariates being negative (all are statistically significant), the net effect (row 11) remains positive and weakly

significant.²³ This net effect indicates that as a whole new Japanese manufacturing sectors appear in the economy no sooner than those in the U.S., and in some cases later.

[Table 2]

Among the covariates, both average firm capital level (row 3) and the capital share of related sectors (row 4) are negatively associated with expected duration. This suggests that new industries with higher invested capital per firm emerge more quickly, and this is especially true for Japan as shown by the positively signed and larger coefficient on the interaction variable (row 6). On the other hand, while more capital invested in related sectors may ease the appearance of new industries in general, perhaps due to greater availability of transferable technology and resources, the effect is reversed in Japan (row 7). This contrasts with industry capital intensity, which has a positive sign on the overall effect, but a negative one when interacted with the Japan fixed effect. One explanation for the latter two interactions is that capital scarcity led to the concentration of resources in fewer, but more capital intensive sectors. This interpretation can further be qualified by the observation that higher capital intensity is derivative of the high cost of capital equipment (i.e., imported) relative to output value in Japan.

Interestingly, the above findings do not carry through to those using the half per cent capital stock threshold as the dependent variable, shown in Table 3. Per capita income (row 1) now is negatively signed, indicating faster growth of manufacturing in wealthier countries. At the same time, the indicator variable for Japan (row 2) is also negatively signed and combined with its interactions with other covariates, the net effect (row 11) is negative and statistically significant. This suggests that Japanese sectors grew to economic significance, with diffusion of embodied technology, relatively faster than those in the United States, even with the inclusion of a time trend to allow for the difference in actual timing.

[Table 3]

Among the covariates, average firm capital (row 3) changes signs and loses significance compared to the previous table and related sector capital share (row 4) has a negative and insignificant coefficient. Only industry capital intensity (row 5) is

²³ The net effect is calculated using a Wald test of the linear combination of all control variables excluding income per capita and year trend, evaluated at the population average for the Japan subset of new industries.

statistically significant but now with a negative sign, while all the interactions with the Japan indicator variable are weakly or not significant. These findings suggest that unlike with the appearance of new industries, their growth is less affected by firm or industry group scale, and that aside from the timing itself, there were no substantive differences between countries as captured by these industry characteristics.

To check the robustness of these results, one can change the period of analysis as well as the capital stock threshold. These results are shown in Tables 4 and 5, respectively. In Table 4, the period of analysis for the United States is shortened by ten years, either by postponing the starting year to 1860 or by advancing the ending year to 1900; the analysis period for Japan remains unchanged. For industry new appearance, changing the benchmark year to 1860 (column A) reduces the number of new industries by nineteen (row 12), but does not affect most of the main results from the full period of analysis in Table 2 (column E). That is, both average firm capital (row 6) and industry capital intensity (row 8) are associated with faster industry appearance in Japan, but the net effect (row 11) remains positive and insignificant. The results from moving the end year to 1900 (column B) replicate those from the earlier table as no new industries appeared in either the 1905 or 1910 economic censuses.

[Table 4]

The different start and end years also do not affect the main results for industries reaching the half per cent capital stock threshold, shown in columns C and D. In both cases, the estimates are similar in magnitude and match in sign and statistical significance, with the net effects indicating faster growth of new industries in Japan, which is associated with overall capital intensity and the size of Japanese firms. The net effect is particularly pronounced with an earlier American end date, which may owe to the longer duration until reaching the capital threshold in the United States and thus censors ten industries from the analysis.

[Table 5]

The second robustness check uses a one per cent total capital stock threshold as a proxy for technological diffusion. These results, shown in Table 5, indicate that while average firm capitalization in Japan still reduces the time to passing the threshold, the net effect is no longer negatively signed. Furthermore, including a time trend variable (column E) increases the magnitude of the positive net effect and is weakly significant, suggesting a longer time to economic significance in relation to the United States. This

finding may be due to the relatively short length of the Japanese industrial data series; when compared to a shorter analysis period for the United States ending in 1900, the net effect becomes insignificant and negatively signed.

CONCLUSION

Given the enormous differences in economic and industrial development between Japan and the United States in the second half of the nineteenth century, it may seem obvious that some convergence between the two countries would occur with sufficient resources and institutions. That Japan did make considerable progress in reducing the gap owes in part to the rapidity of its industrialization and the adoption of technologies developed by industrial pioneers. The results from duration analysis provide evidence that while Japanese industries were able to spread technologies via industry growth more quickly, it is qualified by the relatively slow adoption of new technologies themselves. In other words, technological adoption and diffusion were distinct phenomena in Japan, and even the latter may require longer periods of development than the two decades considered in the analysis.

How does one reconcile these seemingly opposing results? One issue may be the precision of the data, which are still fairly aggregated even at the three-digit industry code level. This may obscure discrete advances in technologies within industry codes as well as the continued use of traditional methods alongside modern ones, as was observed in Japan throughout the late nineteenth century.²⁴ The periods chosen for analysis, based on data availability, may also not be directly comparable since the United States was already fairly industrialized as measured in absolute production by the middle of the nineteenth century. Thus, the technologies adopted in its post-bellum decades could be affected differently by the included covariates than those adopted in Japan, although the standard errors were adjusted to accommodate heterogeneity in sector and country.

Nonetheless, the findings corroborate observations made by Gerschenkron (1964, p. 44) that backward countries will have larger firms and more coordination among them. In all specifications, higher average firm capital stock is associated with earlier entry and growth of Japanese industries compared to the United States, and in

²⁴ Ohkawa and Rosovsky (1973, p. 17) observe that half of all capital goods were still produced using traditional methods in the Meiji Period.

many cases the presence of related sectors (which may serve as competition to new entrants as well as provide organic technological growth opportunities) appears to delay these outcomes.²⁵

At a broader level, one can also observe technological catch up, although possibly not industrial growth, in per capita income differences, with poorer countries adopting new technologies sooner but still requiring additional time for them to attain economic significance. That Japan apparently reverses this relationship, which is not obvious if adoption and diffusion are conflated, may help to explain its success in industrialization compared to its peer group of developing countries. That is, selective adoption of technologies, but with increased resources in those sectors, may have allowed Japan to increase in scale and profitability to compete internationally (e.g., cotton textiles) while laying the foundation for further intensification during the period between the two world wars (Braguinsky et al 2015).²⁶

While the findings of the analysis are suggestive, there are nonetheless a few important limitations that may be fruitful to explore in future work. One extension would be to include factor costs like raw materials and labour, the latter figuring prominently in the expansion of Japanese textiles. This paper partly accounts for this omission by using a measure of capital intensity via production value, but remains silent on the roles of internal labour mobility and differences in productivity, for which there is ongoing research (Fukao et al 2015). Also absent here are discussions of international trade, which may have influenced the types of industries that developed during the period; access to foreign financial capital; and the role of government policy and expenditure, such as the establishment of enterprises in the early Meiji Period and public investments in infrastructure and strategic sectors. With renewed interest in pre-war Japanese economic history and the development of new disaggregated data sources, these issues can be re-examined using more robust statistical techniques.

Regarding the current analysis, these results are consistent with anecdotal accounts and aggregate measures of Japanese technological convergence, and

²⁵ Saxonhouse (1974) attributes the rapidity of technology transfer for cotton spinning to coordination among firms in that sector.

²⁶ One possible objection to this interpretation may be the role of import protection via government procurement or tariff protection, but production in textiles was oriented toward export markets while Japanese tariffs averaged less than 4 per cent before 1900 and less than 8 percent until the 1910s due to treaty impositions dating from the 1850s (Perkins and Tang 2015).

corroborate research dating the country's industrial take-off at the turn of the twentieth century, before most other peripheral economies.²⁷ More generally, the methodology used here can easily be applied to other countries to consistently account for technological change within and between sectors as well as assess relative international differences across space and time.

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²⁷ Abramovitz (1987) notes that convergence between leading and lagging economies was weak prior to 1913. Perkins and Tang (2015) finds that the transition to industrialized status for Japan occurred between 1897 and 1907, indicating that the country's takeoff occurred before then.

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Appendix: List of New Industries

SIC3	Industry Name	Entry Year	
		U.S.	Japan
203	Canned, frozen, and preserved fruits, vegetables, and food specialties		1900
206	Sugar and confectionary products		1895
207	Fats and oils		1890
211	Cigarettes	1870	
212	Cigars	1860	
213	Chewing and smoking tobacco and snuff	1870	
220	Textile mill products		1900
222	Broadwoven fabric mills, manmade fiber and silk		1895
223	Broadwoven fabric mills, wool (including dyeing and finishing)		1895
225	Knitting mills		1900
226	Dyeing and finishing textiles, except wool fabrics		1890
229	Miscellaneous textile goods		1895
230	Apparel and other finished products made from fabrics and similar materials		1910
231	Men's and boys' suits, coats, and overcoats	1860	
232	Men's and boys' furnishings, work clothing, and allied garments	1880	
233	Women's, misses', and juniors' outerwear	1860	
235	Hats, caps, and millinery		1900
236	Girls', children's, and infants' outerwear	1870	
242	Sawmills and planing mills		1890
243	Millwork, veneer, plywood, and structural wood		1890
244	Wood containers		1905
249	Miscellaneous wood products		1890
250	Furniture and fixtures	1870	
251	Household furniture		1890
254	Partitions, shelving, lockers, and office and store fixtures	1860	
259	Miscellaneous furniture and fixtures	1860	
260	Paper and allied products		1895
271	Newspapers: publishing, or publishing and printing	1870	
273	Books	1870	
277	Greeting cards	1860	
285	Paints, varnishes, lacquers, enamels, and allied products		1890
287	Agricultural chemicals	1860	1890
289	Miscellaneous chemical products		1895
295	Asphalt paving and roofing materials	1860	1910
299	Miscellaneous products of petroleum and coal		1890
300	Rubber and miscellaneous plastics products		1900
302	Rubber and plastics footwear	1880	
305	Gaskets, packing, and sealing devices and rubber	1880	
306	Fabricated rubber products, not elsewhere	1860	

308	Miscellaneous plastics products	1880	
322	Glass and glassware, pressed or blown	1860	1890
323	Glass products, made of purchased glass	1860	
324	Cement, hydraulic		1890
325	Structural clay products		1890
328	Cut stone and stone products		1890
329	Abrasive, asbestos, and miscellaneous nonmetallic mineral products		1900
330	Primary metal industries		1895
331	Steel works, blast furnaces, and rolling and finishing mills		1890
332	Iron and steel foundries		1895
333	Primary smelting and refining of nonferrous metals		1900
334	Secondary smelting and refining of nonferrous metals	1860	
335	Rolling, drawing, and extruding of nonferrous metals	1860	
343	Heating equipment, except electric and warm air		1910
347	Coating, engraving, and allied services		1910
349	Miscellaneous fabricated metal products		1910
350	Industrial and commercial machinery and computer equipment	1870	
352	Farm and garden machinery and equipment		1890
353	Construction, mining, and materials handling	1860	
354	Metalworking machinery and equipment	1860	1900
357	Computer and office equipment	1880	
358	Refrigeration and service industry machinery	1860	
359	Miscellaneous industrial and commercial equipment	1860	1890
360	Electronic and other electrical equipment and components, except computer equipment	1860	
362	Electrical industrial apparatus	1880	1905
364	Electric lighting and wiring equipment		1890
365	Household audio and video equipment, and audio media	1900	
370	Transportation equipment		1890
371	Motor vehicles and motor vehicle equipment		1900
373	Ship and boat building and repairing		1890
374	Railroad equipment		1905
382	Laboratory apparatus and analytical, optical, measuring, and controlling instruments		1890
387	Watches, clocks, clockwork operated devices, and parts		1895
394	Dolls, toys, games and sporting and athletic goods	1860	
395	Pens, pencils, and other artists materials		1900

Source: United States Office of Management and Budget (1987) and author's calculations. Years are rounded forward on a five-yearly basis for Japanese industries.

Figure 1: Number of New SIC3 Industries in the U.S. and Japan

Source: see text

Figure 2: Survival Curves of New Industry Appearance in the U.S. and Japan

Source: see text.

Table 1: Industrial Development in the U.S. and Japan

United States	1850	1860	1870	1880	1890	1900	1910
GDP (mil)	\$2,581	\$4,387	\$7,812	\$10,462	\$15,223	\$20,766	\$33,746
Population (mil)	23.3	31.5	39.9	50.3	63.1	76.1	92.4
Manufacturing Industries	251	605	383	277	305	314	256
SIC3 Sectors	95	108	109	105	107	107	101
New SIC3 Sectors		19	7	6	0	1	0
Firms	114,774	128,574	230,330	176,788	200,128	207,176	268,440
Average Firm Capital	\$4,234	\$7,279	\$8,980	\$15,255	\$30,348	\$43,201	\$71,815
Japan		1885	1890	1895	1900	1905	1910
GNE (mil)		\$9.6	\$12.6	\$30.7	\$49.0	\$62.5	\$79.5
Population (mil)		38.3	39.9	41.6	43.8	46.6	49.2
Manufacturing Industries		24	48	52	73	82	93
SIC3 Sectors		18	37	39	49	52	58
New SIC3 Sectors			20	9	10	3	5
Firms		498	2,055	831	2,344	2,325	3,489
Average Firm Capital		\$99	\$190	\$1,063	\$1,602	\$1,261	\$2,181

Source: see text.

Table 2: Duration Model Results for New Industry Appearance

DV: Log(Years to New SIC3 Industry)	A	B	C	D	E
Log(Per Capita Income) (Current US\$)	0.138 (0.106)	0.284*** (0.102)	0.263*** (0.102)	0.374*** (0.116)	0.339 (0.261)
Country Fixed Effect (Japan = 1)	0.481 (0.615)	1.242** (0.592)	0.957 (0.610)	1.820** (0.717)	1.531 (2.113)
Average Firm Capitalization (Current US\$)		-0.007*** (0.001)	-0.007*** (0.001)	-0.008*** (0.001)	-0.008*** (0.001)
Capital Share of Related SIC3 Industries (%)			-0.056** (0.027)	-0.057** (0.028)	-0.055** (0.028)
SIC3 Capital Intensity				0.015*** (0.006)	0.015*** (0.005)
Country F.E. x Average Firm Capitalization		-0.177*** (0.042)	-0.175*** (0.043)	-0.164*** (0.038)	-0.164*** (0.038)
Country F.E. x Related SIC3 Capital Share			0.057** (0.028)	0.057** (0.028)	0.055** (0.028)
Country F.E. x SIC3 Capital Intensity				-1.535** (0.702)	-1.529** (0.705)
Year trend					0.003 (0.020)
Constant	2.370*** (0.555)	1.780*** (0.535)	2.048*** (0.554)	1.479** (0.621)	-4.252 (35.993)
Net Effect (Japan)		1.002* (0.607)	0.723 (0.624)	1.286* (0.692)	0.998 (2.094)
Total Industries/Event Occurrence	80/80	80/80	80/80	80/80	80/80
Observations	160	160	160	160	160
Log Pseudolikelihood	294.167	299.951	300.634	302.438	302.451
Chi-squared Statistic	201.87***	185.98***	158.83***	577.21***	603.11***

Significance levels: *10%, **5%, ***1%.

Source: see text. All specifications use robust standard errors clustered by SIC3 industry and country (in parentheses).

Table 3: Duration Model Results for Industry Growth

DV: Log(Years to 0.5% Mfg. Capital Stock)	A	B	C	D	E
Log(Per Capita Income) (Current US\$)	-0.773*** (0.155)	-0.621*** (0.162)	-0.671*** (0.178)	-0.572*** (0.188)	-0.390* (0.231)
Country Fixed Effect (Japan = 1)	-5.512*** (0.978)	-4.657*** (1.026)	-5.097*** (1.210)	-5.156*** (1.270)	-3.791** (1.596)
Average Firm Capitalization (Current US\$)		-0.001*** (0.0003)	-0.001*** (0.0003)	0.001 (0.001)	0.0005 (0.001)
Capital Share of Related SIC3 Industries (%)			-0.009 (0.021)	-0.018 (0.023)	-0.022 (0.024)
SIC3 Capital Intensity				-1.183*** (0.348)	-1.015*** (0.380)
Country F.E. x Average Firm Capitalization		-0.054* (0.029)	-0.050 (0.032)	-0.054* (0.031)	-0.059* (0.031)
Country F.E. x Related SIC3 Capital Share			0.016 (0.022)	0.024 (0.024)	0.028 (0.025)
Country F.E. x SIC3 Capital Intensity				0.711 (0.763)	0.496 (0.759)
Year trend					-0.010 (0.009)
Constant	7.451*** (0.878)	6.735*** (0.902)	7.044*** (1.026)	7.251*** (1.073)	25.499 (15.873)
Net Effect (Japan)		-4.755*** (1.006)	-5.110*** (1.153)	-5.286*** (1.191)	-3.948*** (1.534)
Total Industries/Event Occurrence	74/74	74/74	74/74	74/74	74/74
Observations	336	336	336	336	336
Log Pseudolikelihood	265.231	267.619	267.901	270.563	270.927
Chi-squared Statistic	47.87***	92.51***	90.37***	88.51***	85.04***

Significance levels: *10%, **5%, ***1%.

Source: see text. All specifications use robust standard errors clustered by SIC3 industry and country (in parentheses).

Table 4: Robustness Check, Varying Periods of Analysis

DV: Log(Years to Event Occurrence)	A	B	C	D
	New Industry	0.5% Capital	New Industry	0.5% Capital
Log(Per Capita Income) (Current US\$)	0.266 (0.314)	0.339 (0.261)	-0.323 (0.238)	-0.489** (0.241)
Country Fixed Effect (Japan = 1)	0.992 (2.493)	1.531 (2.113)	-3.407** (1.627)	-5.024*** (1.788)
Average Firm Capitalization (Current US\$)	-0.008*** (0.002)	-0.008*** (0.001)	0.0005 (0.001)	-0.004 (0.004)
Capital Share of Related SIC3 Industries (%)	-0.138 (0.095)	-0.055** (0.028)	-0.038 (0.035)	-0.020 (0.023)
SIC3 Capital Intensity	0.017*** (0.006)	0.015*** (0.005)	-0.974*** (0.353)	-1.017** (0.456)
Country F.E. x Average Firm Capitalization	-0.156*** (0.038)	-0.164*** (0.038)	-0.058* (0.033)	-0.065** (0.031)
Country F.E. x Related SIC3 Capital Share	0.138 (0.095)	0.055** (0.028)	0.043 (0.036)	0.024 (0.024)
Country F.E. x SIC3 Capital Intensity	-1.405* (0.724)	-1.529** (0.705)	0.474 (0.743)	0.269 (0.769)
Year trend	-0.003 (0.027)	0.003 (0.020)	-0.016 (0.012)	0.011 (0.012)
Constant	7.002 (48.444)	-4.252 (35.993)	36.687 (22.850)	-14.128 (21.601)
Period of analysis (U.S.)	1860-1910	1860-1910	1850-1900	1850-1900
Net Effect (Japan)	0.493 (2.475)	0.998 (2.094)	-3.560** (1.564)	-5.260*** (1.745)
Total Industries/Event Occurrence	61/61	80/80	62/62	74/64
Observations	122	160	236	324
Log Pseudolikelihood	235.420	302.451	236.632	227.395
Chi-squared Statistic	1022.33***	603.11***	72.56***	64.32***

Significance levels: *10%, **5%, ***1%.

Source: see text. All specifications use robust standard errors clustered by SIC3 industry and country (in parentheses).

Table 5: Robustness Check, Higher Total Capital Stock Threshold

DV: Log(Years to 1% Mfg. Capital Stock)	A	B	C	D	E
Log(Per Capita Income) (Current US\$)	-0.005 (0.243)	0.314 (0.232)	0.284 (0.244)	0.313 (0.290)	0.730* (0.378)
Country Fixed Effect (Japan = 1)	0.306 (1.374)	1.940 (1.346)	1.745 (1.433)	1.354 (1.767)	4.405* (2.462)
Average Firm Capitalization (Current US\$)		-0.005*** (0.001)	-0.005*** (0.001)	-0.004*** (0.001)	-0.003*** (0.001)
Capital Share of Related SIC3 Industries (%)			-0.033 (0.024)	-0.051** (0.026)	-0.055* (0.029)
SIC3 Capital Intensity				-0.750** (0.370)	-0.465 (0.425)
Country F.E. x Average Firm Capitalization		-0.187** (0.083)	-0.182** (0.082)	-0.187** (0.081)	-0.197** (0.081)
Country F.E. x Related SIC3 Capital Share			0.015 (0.026)	0.033 (0.027)	0.036 (0.030)
Country F.E. x SIC3 Capital Intensity				0.848 (1.079)	0.430 (1.137)
Year trend					-0.023* (0.012)
Constant	3.551*** (1.321)	2.156* (1.244)	2.520* (1.348)	2.910* (1.561)	44.242** (21.981)
Net Effect (Japan)		1.727 (1.330)	1.387 (1.422)	1.010 (1.634)	4.020* (2.330)
Total Industries/Event Occurrence	84/52	84/52	84/52	84/52	84/52
Observations	410	410	410	410	410
Log Pseudolikelihood	150.024	158.468	159.879	160.780	161.964
Chi-squared Statistic	1.97	58.99***	64.03***	93.32***	109.69***

Significance levels: *10%, **5%, ***1%.

Source: see text. All specifications use robust standard errors clustered by SIC3 industry and country (in parentheses).