History and Nanoeconomics in Strategy and Industry Evolution Research: Lessons from the Meiji-Era Japanese Cotton Spinning Industry

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Abstract

This paper uses nanoeconomics and historical methodology to advance strategic management research, focusing on the coevolution of firms and industry. We demonstrate the power of these methods through a study of Meiji Era Japanese cotton spinning industry from its state-supported founding through its development into a sustained, globally competitive presence. We shed light on the role of superior human and organizational capabilities of industry leaders. In particular, we demonstrate that these helped the industry leaders to overcome deep, systematic structural factors to make a few firms highly productive and able to move the entire industry into high growth and to respond to and thrive in dynamic environments on the world stage.

Running head: History and Nanoeconomics in Strategy and Industry Evolution
Keywords: Historical methodology, Nanoeconomics, Nanoeconomic analysis, Industry evolution, Japanese cotton spinning industry

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'Nobody can hope to understand the economic phenomena of any, including the present, epoch who has not an adequate command of historical *facts* and an adequate amount of historical *sense*.'
(Schumpeter, 1954, pp. 12-13.)

'Nano-economics . . . involves digging below the microeconomic level to understand the evolution of industries.'
(Klepper, 2011, p. 143)

Introduction and related literature

This paper uses nanoeconomics and historical methodology to advance strategic management research, focusing on the coevolution of firms and industry. Building on Klepper (2011), we define 'nanoeconomics' as the practice of developing, working with, and analyzing data at levels below those customarily employed in microeconomics so as to reveal fundamental phenomena underlying the sources of firm heterogeneity and the coevolution of firms and industries. These collections of data, which we call 'nanoeconomic databases,' capture such information as firm founders and key employees; their educational and employment histories, professional networks, and intellectual property; and the institutions and organizations, including government, in and with which firm founders and firm employees work and interact. 'Nanoeconomic analysis' is therefore defined as employment of economic, econometric, and other quantitative social science methods to analyze the contents of nanoeconomic databases so as to understand phenomena associated with firm establishment and the evolution of industries at their most fundamental level.

The proposed definitions make it clear that nanoeconomics in general and the construction of nanoeconomic databases in particular require deep archival research, making use of historical methodology. This work often requires the researcher to operate at levels of detail far finer than academic historians are accustomed in their traditionally qualitative methods

(Klepper, 2016). When built up in this way, nanoeconomic analysis greatly facilitates the consideration of a mix of causal factors, including those driven by individuals, firms, and other organizations such as industry associations and governments, as well as outlier activities and the broad historical and institutional context in which firms and industry coevolve. Nevertheless, historical methodology remains underutilized in strategy research (Murmann, 2012). Our search through the last decade of issues of this journal turned up only one paper—on the early U.S. bicycle industry—that actually makes use of historical data (Dowell and Swaminathan, 2006). One reason could be that historical methodology is too often associated with taking deep dives into single cases or tracing a small number of phenomena over long periods, supported at best by 'analytical narratives' (Ingram, Rao, and Silverman, 2012; Kahl, Silverman, and Cusumano, 2012). Practitioners of historical method seldom combine these tools with rigorous traditional empirical methods that allow the measurement or testing of causal factors and conclusions.

From the point of view of strategic management, nanoeconomic methodology allows us to identify decision-makers directly responsible for strategic choices and the factors that separate them from other decision-makers. This helps the researcher to avoid various potential problems, such as aggregation bias, misspecification from attributing an observed relationship or outcome to a level other than the true one (Rousseau, 1985, pp. 5–9), as well as the hindsight, or 'historicism' bias, where things that actually happened are interpreted as being more pre-determined or inevitable than they actually were (Fischoff, 1980; Kirsch, Moeen, and Wadhawali, 2013). We present several examples in the paper of how our methodology can safeguard against these potential biases.

The current paper demonstrates the power of nanoeconomics combined with historical methodology and quantitative empirical analysis through a study of the coevolution of firms and industry in Meiji Era Japanese cotton spinning industry. The remarkable story of this industry has been told by economic historians (e.g., Landes, 1965; Saxonhouse, 1974; Fletcher, 1996), but to the best of our knowledge, an in-depth examination of the role played by intra-industry 'discretionary differences' across heterogeneous firms (Nelson, 1991) has not been previously attempted. In this study, we make use of the nanoeconomic database on the industry built by Braguinsky in collaboration with Japanese colleagues, Atsushi Ohyama, and Tetsuji Okazaki.[3] Two other papers, the work on which progressed in parallel to this one (Braguinsky, Ohyama, Okazaki, and Syverson, 2015; Braguinsky and Hounshell, 2015), focus on different aspects of this story while drawing on parts of the same database. Distinct from those other papers, the current paper presents a detailed, nanoeconomic picture of industry evolution through the lens of firm-level strategic decision-making spanning three stages of industry evolution (cf. Gort and Klepper, 1982)—the early stage (until about 1890); the stage of mass entry and explosive growth (most of the 1890s); and the "shakeout" and industry consolidation stage (the 1900s). We focus on the heterogeneity of strategic decisions taken at the firm level, the individuals behind this heterogeneity, and the interaction between firm-level strategic decisions and industry evolution, which was both shaping those and, in turn, shaped by them.

The concept of firm heterogeneity has traditionally focused on differences in firms' resources and/or (dynamic) capabilities, understood primarily as outcomes of firm-specific process of accumulation of tangible and intangible assets, and organizational routines over time (Nelson, 1991; see also Teece and Pisano, 1994; Teece, Pisano, and Shuen, 1997; Helfat, Filkenstein, Mitchell, Peteraf, Singh, Teece, and Winter, 2007). Without denying the importance of these factors, our findings draw attention to the crucial importance of *inherent* firm heterogeneity. Important strategic choices diverged across firms right from the outset, even as

[3] A description of the database and how it was constructed is presented in the online appendix.

they all faced the same external environment. The nanoeconomic database allows us to trace these differences to differences in the human capital of founding team members, including but not limited to differences stemming from pre-entry experience and education (cf. Mitchell, 1989, and 1991; Carroll *et al.*, 1996; Klepper and Simons, 2000; Beckman, 2006; Braguinsky, Klepper, and Ohyama, 2012). We also demonstrate that at several junctures in the evolution of technology and market environment, these same differentials played out *predictably* in the same way, increasing the long-term advantage of firms led by innovating teams and punishing firms that were founded by non-innovating teams and by later imitators alike, even when it initially seemed that environmental changes might favor later over earlier entrants.

In shining a spotlight through our differential analysis on decision-making individuals, even within similar firm categories, the current paper suggests that government technical assistance, provided with authority not backed by competence, leads to even worse outcomes than no such assistance at all. Also, while past research has identified the important role of acquiring tacit knowledge through direct contact with the technological frontier (i.e., the British cotton-spinning industry at the time—see Saxonhouse, 1974; Braguinsky and Hounshell, 2015), our investigation shows that it was effective only when combined with other important strategic management decisions, such as choosing incorporation to raise capital for a minimum efficient production scale. Finally, we demonstrate that changes in the environment, which are traditionally considered to be a given for any individual firm in both economics and the strategic management literature, were actually largely themselves the product of strategic choices made by a handful of industry-leading firms. We show that the decisions formulated and strategic actions executed by those firms changed the trajectory of the industry's evolution. We also demonstrate that those (and only those) firms characterized by constant experimentation 'ahead of the curve' and accumulation of technological and managerial competencies beyond the immediate needs of the day were successful when the environment changed exogenously (cf. Patel and Pavitt, 1997; Hobday, 1998; and Brusoni, Prencipe and Pavitt, 2001). The upshot of our analysis is that entrepreneurial imagination, foresight, and willingness to experiment were the most important factors in both individual firm outcomes and overall industry development.

Although the focus of our paper is very context specific—late 19th- and early 20th-century Japanese cotton spinning—we believe that the methods we employ and the processes we identify and measure are meaningfully generalizable. One can cite numerous examples of independent strategic choices made by a handful of outliers (or even by a single standout entrepreneur) dramatically changing the 'face' of the industry or even creating an entirely new one. Indeed, in 1903, the year Ford Motor Company was founded, France was the world's leading automaker, producing almost half of the total world's cars (almost 3 times more than the U.S.). Within a dozen years, Ford would dominate world automotive production through both bold product and radical process innovation, the latter of which would become the dominant manufacturing paradigm for the industry. Almost 100 years later, Steven Jobs's 'reality distortion field' was credited with creating digital music delivery and smartphone industries where none had existed before (Isaacson, 2011; for more similar stories see Hounshell, 1984; Ferraro and Gurses, 2009; Cusumano, 2012).

There is also evidence that even the best-intended efforts to introduce technological, organizational, and managerial practices that have worked elsewhere often lead both firms and whole industries down blind alleys because not enough attention has been paid to securing the right kind of human capital. Thus, the British government tried to create its own dyestuffs industry during World War I by replicating the elements of success in the organization of the

German industry but, as one contemporary observer wrote, 'has made use of entirely unskilled agents—and, as was to be expected, the failure has been complete' (*Science*, Vol. 68, No. 1239, 1918, p. 314). History is littered with countless such examples, from unsuccessful technology transfer in the Ghana aluminum industry (Easterly, 2001) to the most recent Skolkovo ('Silicon Valley') project in Russia (see Lerner, 2009, for a thoughtful analysis of a large number of such cases).

Careful reconstruction of the history of producer entry and exit, innovation and patenting activities, prices, and output dynamics has, of course, been the hallmark of industry evolution literature from its very inception (Gort and Klepper, 1982; Aragwal and Gort, 1996; Klepper and Simons, 2000). The notion that firm and industry histories need to be incorporated into strategy is also rooted in Chandler's classical work (Chandler, 1962), Nelson and Winter's landmark book on evolutionary economics (Nelson and Winter, 1982), and notions of path dependency of W. Brian Arthur (Arthur, 1989), Paul David (David, 1992), and David Teece (1988). Of course, these ideas are even more deeply rooted in the corpus of Joseph Schumpeter's thought and work (Schumpeter, 1911; Schumpeter, 1942; Schumpeter, 1954).

Throughout this study, we seek to illustrate transparently the most important point about the methodology of question-driven research: the enormous gains to be had in building comprehensive nanoeconomic databases and exploiting their analyses. We argue that the nanoeconomic approach provides the means for scholars in strategy to understand the nature and consequences of strategic choice in industry evolution more fundamentally than is typical using microeconomic analysis on the one hand or purely historico-qualitative analysis on the other. Our distinct contribution is thus both methodological and empirical.

What does it take to change the environment? Breaking the spell of backwardness

In the 'big picture,' the Japanese cotton spinning industry presents a rare example of a developing country's almost seamless adoption of advanced Western manufacturing techniques and creation of a globally competitive industry in a distinctively short period of time. As the late Japan specialist Gary Saxonhouse wrote so trenchantly, 'The astonishing ascendance of Osaka over Lancashire stands as the first completely successful instance of Asian assimilation of modern Western manufacturing techniques' (Saxonhouse, 1974, p. 150). The process started under Meiji government auspices in the late 1870s. The government considered this a top priority because growing imports of cotton yarn and clothing were draining the country's specie (see, e.g., Kogyo Ikensho, 1884, reprinted in 1969, pp. 487-489). With the externally-imposed prohibition on protective tariffs, the government decided to promote the industry by creating 'model mills' and subsidizing over a dozen more by purchasing British spinning machinery and reselling it at subsidized prices and with easy loan terms. These efforts have sometimes been credited with helping the industry to overcome the initial difficulties of industrialization (e,g., Smith, 1955, p. 63; Landes, 1965, p. 102). And even when researchers realized that government-subsidized mills failed, they argued that these efforts 'produced important demonstration effects and trained many skilled artisans and managers' (Rodrik, 2014, p. 83), thus contributing to knowledge diffusion that sparked subsequent spectacular industry growth. In this section, we subject this view to nanoeconomic scrutiny to identify exactly what the government-promoted part of the industry accomplished in terms of technological advances and where the knowledge and training that led to the industry success actually derived.

Government support for the industry was discontinued in 1886 (more on this below), so this year, which, not coincidentally, was anointed as the first year of the 'modern economic growth era' in Japan (Ohkawa, and Rosovsky, 1965, p. 66), presents a natural benchmark against which to measure the role played by government efforts at technology diffusion going forward. The primary evidence for the contention that government-aided mills played an important role in the Japanese cotton spinning industry was based on a simple observation that most mills in 1886 (the beginning of modern growth era for the industry) had government-sponsored origins and that four years later spindleage had increased by 200 percent while the number of spinning mills had increased by only 33 percent. This is an example of aggregation bias from ignoring various levels of analysis (Rousseau, 1985), and it was first debunked by the late Gary Saxonhouse using firm-level data showing that most of the increase in these four years came from privately sponsored mills (Saxonhouse, 1974, p. 151). In fact, our newly added 1886 firm-level data show that this bias already manifests itself in the assessment of the data for that year. In 1886, there were 21 mechanized cotton spinning mills operating in the industry, running 3,182 spindles on average and employing on average 75 factory operatives. These average numbers are all but meaningless, however. Just one mill, Osaka Spinning Company, *which did not have government-sponsored origin*, operated 16,320 spindles, employed 402 operatives, and produced about 40 percent of total industry output. The remaining 20 mills, all of a similar size, operated on average less than 2,340 spindles and employed on average almost 53 operatives.[4] The gap in terms of efficiency was also large; Osaka Spinning Company was among the few mills that operated without stoppages, and even conditional on operating, its labor productivity (output in physical units, adjusted to the 20^{th} count and divided by work-hours) was 15 percent and its

[4] Unless explicitly stated otherwise, all the data here and below are our calculations or estimates using the data sources described in the online appendix.

capital productivity (output in physical units, adjusted to the 20th count and divided by spindle-hours) was 25 percent higher than the average of the other 20 mills in the same year.[5]

Information on firms' origins allows us to go beyond simply comparing firm sizes and other outcomes and to link specific technological choices to individuals in charge.[6] In particular, we know that government-led knowledge dissemination was conducted early on through an industry association (hereafter, 'Boren'). At the time, the association was managed by the government and the technology 'guru' in charge was Masatatsu Ishikawa (1825-1895). Ishikawa had studied in Nagasaki (the only port city in Japan open for trade and cultural exchange with the West at the time) some 20 years before Meiji Restoration. He had neither training as an engineer nor any experience in cotton spinning (whatever studies in engineering he completed while at Nagasaki appear to have been in military artillery). Nevertheless, he became the Meiji government's technology emissary in diffusing mechanized cotton spinning throughout Japan.

In the late 1870s, the government ordered Ishikawa to set up the Aichi National Mill, a brand-new plant in a rural area 30 miles outside of Nagoya in present-day Aichi prefecture, designed to become the flagship of the government-promoted cotton spinning industry. Seventeen more mills, either directly owned by the government (including prefectural governments) or subsidized by it, started operating throughout Japan between 1882 and 1885. Ten of those were designed, assembled, and started up under Ishikawa's supervision or that of his subordinates. Seven other mills, also receiving government financial support, were not guided by Ishikawa, however, and relied on whatever technicians could be recruited as well as advice they obtained from another pioneering firm, Kashima Spinning, founded in Tokyo in 1865 without direct support from the government.

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[5] The yarn count expresses how many yards are contained in a pound of yarn, so it reflects the yarn thickness. Higher-count yarn is thinner (finer) and sells at a higher price per pound than lower-count yarn.
[6] The narrative here draws in part on Braguinsky (2015), to which the reader is referred for more details.

As already noted, no government-promoted firms had any success until 1886 (and after that, as shown below, only few were even temporarily successful). Firms that received directions from Ishikawa and his subordinates and apprentices fared even worse than other government-promoted firms. Ishikawa promoted deeply flawed technologies, leading all his mills down a blind alley. For example, he insisted on using hydro as the main source of power, which resulted in mills located in remote, often mountainous areas, exposing them to chronic seasonal power shortages—and, therefore, low capital productivity as well as major labor problems. In Table 1 we summarize the technology choices made by mills in terms of the number of spindles installed, water power versus steam engine, capital-to-labor ratios (defined as the number of spindles in operation, divided by the number of operatives employed in each month), and the ratios of female-to-male factory operatives at Ishikawa-directed and other government-aided mills. We use all available monthly data for years 1883–1886 (that is, during the whole period of government support) and take the means over all months. As can be seen, while the sizes of all mills are similar (just barely above 2,000 spindles, reflecting the overall government policy of subsidizing 2,000-spindle mills across the country), other technology choices present stark differences. In our observations, we see that water was the main source of power in 70 percent of the mills implemented by Ishikawa but in less than 26 percent of mills not implemented by him. Table 1 also shows that mills directed by Ishikawa were significantly more capital-intensive and tended to employ more female operatives relative to male operatives than other mills. The best practices subsequently established in the industry involved labor-intensive production technology, coupled with a high share of female operatives in the workforce. Running capital-intensive mills while relying extensively on female labor pushed the industry in the wrong direction. Of course, high capital intensity may also have been an unintended consequence of difficulties in recruiting labor in remote locations. Still, the wrong technological choice (hydro as the source of power) was at the root of the problem.

[Table 1 around here]

The consequences show up in productivity outcomes. To capture the latter, we regress several outcome variables on the dummy equal to 1 if the firm was directed by Ishikawa and 0 otherwise, controlling for year-month fixed-effects. The sample covers all government-aided firms (but excludes non-government-aided firms such as Osaka Spinning Company) and covers all available monthly data from 1883–1886. The estimation equation is

$$y_i = \alpha + \beta D_i + \mu_t + \epsilon_{it}, \quad (1)$$

where y_i is the outcome variable, D_i is the dummy variable, μ_t is the year-month fixed effect, and ϵ_{it} is the firm-specific random error term. Outcome variables are logged labor productivity (monthly output in weight units, divided by the total number of worker-days employed) and logged capital productivity (monthly output in weight units, divided by the total number of spindle-days in operation). We also estimated the production function with logged output as a function of logged capital input, logged labor input, and year-month fixed effects and used the residuals from this estimation as a measure of total factor productivity, which is then used as the outcome variable in regression (1).

The estimation results are presented in Table 2. Average capital productivity of the mills guided by Ishikawa is estimated to be about 25 percent (exp(-0.288)–1) below that of firms that were not guided by him (statistically highly significant); average labor productivity is lower by about 10 percent (statistically significant at the 5 percent level). Total productivity of Ishikawa-guided mills is about 16 percent lower on average than that of mills he did not work with.

[Table 2 around here]

Choosing an individual with insufficient human capital to lead the industry was not the only strategic mistake of the government. Another was to use domestically grown cotton. In addition to being permanently in short supply, with a staple length of just 5/8 of an inch (Saxonhouse and Wright, 2010, p. 562), Japanese-grown cotton was simply too short to be effectively transformed into quality cotton yarn using Western mechanized technology. It was not just ignorance that led to this decision, because the problem of spinning short-staple cotton was actually well understood even at the time (see Nawa, 1937). The government's grand design—coupling industrial policy with agricultural policy—was at fault; it called for as many as 250 small 2,000-spindle cotton spinning mills in cotton-producing areas of Japan (estimated to yield the equivalent amount of yarn that Japan was importing in 1878; Takamura, 1971, vol. I, p. 45). This fantastic plan wedding agricultural and industrial policies never fully materialized. But in accordance with its blueprint, all 20 of the spinning mills established under government auspices conformed to the envisaged small-scale mill (i.e., 2,000-spindles) and were scattered throughout the country.

In this historical context, the emergence of Osaka Spinning Company looks almost like divine intervention. But we know exactly who the humans behind Osaka Spinning Company's remarkable story were and what they did differently from everybody else in this industry at the time. The company was founded in 1882, about the same time as the majority of government-sponsored mills, although planning for it had begun in 1879. Its founder, pioneering industrialist Eiichi Shibusawa, was approached several times by the government to start a government-supported mill but he refused and chose instead to set up his enterprise according to his own vision (Shibusawa Eiichi Denki Shiryo, 1956, Vol. 10, p. 16). Osaka Spinning Company's rise is a striking example of how a single firm can provide a new blueprint for an entire industry.

First, Shibusawa realized that he needed to obtain his own technologically enlightened human capital. He thus recruited a young man, Takeo Yamanobe, who had earlier gone to England to study the insurance business at the University of London. Yamanobe transferred to the mechanical engineering department at Kings College, Cambridge, and then went to acquire manufacturing knowledge at Rose Hill Mill in Blackburn, Lancashire (Abe, 2004). Through financial incentives (amounting to tens of thousands of dollars in today's money) paid by Shibusawa, the owner of Rose Hill Mill also gained access for Yamanobe to inspect other cotton mills in the region during the course of his apprenticeship. As is well known, Yamanobe became the chief engineer and later the CEO of Osaka Spinning Company. In 1888 he also became the chairman of the industry association Boren and reoriented its knowledge diffusion system to accord with his experience in Lancashire and Osaka Spinning. Even though some historians have discounted Yamanobe's role, arguing that all what he did was to slavishly imitate the British, the question remains what had prevented government technicians from doing the same years earlier.

Second, Shibusawa's technology plan envisaged constructing a much larger mill than the government-promoted 2,000-spindle size right from the beginning (Takamura, 1971, Vol. I, p. 64). The first issue that had to be addressed, of course, was securing enough capital. Shibusawa drew on his prior experience as the founder of Japan's first modern bank to establish a joint stock company and proceeded to raise capital from a broad and diverse array of private investors. The initial list of Osaka Spinning Company's shareholders counted 95 individuals, the largest of whom (Shibusawa himself) owned 12 percent of the total number of shares. Raising all the initially planned capital turned out to be difficult even for someone like Shibusawa; his initial plan had been to open the mill with 12,000 spindles, but he was forced to start with 10,500 instead (Takamura, 1971, Vol. I, pp. 66–67). Though not a technological but a managerial innovation, the joint stock company organization proved to be extremely important (see below).

The contacts that Yamanobe established in Lancashire allowed him to draw on an entirely different, globally connected knowledge base than that of the government-aided mills. Osaka Spinning's new two-story brick factory, the first private facility in Japan lit by electricity, became a source of admiration (and subsequent imitation) throughout the industry. Different (and superior) technological choices were made with regard to the mill's spinning machinery as well. Ishikawa had chosen William Higgins and Sons as the supplier for all government-aided mills, but its machines were not designed for Japan's short-staple raw cotton (Tamagawa, 1995). Yamanobe worked directly with Platt Brothers of Oldham to customize their machines so that they could be adjusted as much as possible to handle short-staple domestically grown cotton (Farnie and Abe, 2000). Moreover, realizing the limits of his own knowledge at the time, Yamanobe invited William Nield, a veteran Platt Brothers engineer and millwright with international experience, to guide his installation team. One of the young Japanese assigned to help Nield in this process (and to learn from him), Katsumasa Okamura, subsequently recalled, 'Nield … had extremely precise knowledge of the technology and was also a very good teacher. All previous mills had been assembled by uneducated workers, guided by people who … themselves possessed only half-baked knowledge. Ours was … the first time a Japanese cotton spinning mill started operating after being properly assembled and installed, and it made a huge difference' (quoted in Toyo Boseki, 1986, Vol. I, p. 26).

This historical episode demonstrates that the enlargement of firms' strategy space through markets for technology (see Arora, Fosfuri, and Gambardella, 2001, p. 421; Arora and Gambardella, 2010) can happen in more than one way, including through equipment suppliers and consultants diffusing technology to customers willing to pay for it. Other far-sighted entrepreneurs followed Osaka Spinning's example. For example, the contract made in 1888 by Hirano Spinning and Mie Spinning with Thomas Dransfield, an engineer sent to Japan by Platt Brothers, stipulated a weekly salary of seven pounds 10 shillings (Okamoto, 1995, p. 123). Using the London exchange rate (Meiji Taisho Kokusei Soran, 1975, p. 156), this corresponds to the base salary of 50 yen per week, or about the same as a monthly salary of a top-notch native engineer. (In addition, the contract stipulated overtime pay and the provision of free housing and household goods.) In the long run, just as in Osaka Spinning's case, paying the price for an opportunity to tap into cutting-edge global knowledge sources paid off in terms of higher productivity, profitability and survival.[7]

Osaka Spinning Company started operating in 1883 and was the only profitable company in the industry at the time. Much of those profits was distributed as dividends to shareholders (which reached as high as 18–20 percent per year in the first few years), demonstrating clear awareness of the importance of building investors' confidence. As a result, the company was able to triple its raised capital (and corresponding mill size) within just a few years, reaching a 30,000-spindle capacity by late 1886. As already mentioned, that was the year the government finally decided to terminate its promotion policies and to let the industry develop on its own. In the government's own account, the primary reasons for such a decision were the lack of performance, slow technological advancement among government-promoted firms, and the stark contrast its mills presented to what private Osaka Spinning Company was able to accomplish under the same conditions (Enkakukiji, 1901, chapter 1).

[7] Interestingly, as the Japanese cotton textile industry matured, it turned the tables on Platt Brothers. In 1929, it was Platt Brothers that paid £100,000 for the patent rights for an innovative automatic loom designed by Toyoda Automatic Loom Works. The money was used as part of the start-up capital for Toyota Motor Company.

Industry-wide technological catch-up through the prism of strategy choices

Despite Osaka Spinning Company's impressive innovations and performance, the industry took off only after the government terminated its support and intervention policies in 1886 (Figure A1 in the online appendix). The next year alone saw the founding of eleven new private firms, all joint stock companies. In this section, we show how our methodology allows us to attribute the causal factors behind this growth to a handful of firms in this cohort of new and early private entrants and the individuals employed by them, while at the same time exposing and correcting a few more fallacies coming from decision-level misspecification.

The story that (in its broad outlines correctly) traces the roots of the industry's success to innovations by the Osaka Spinning Company is nevertheless incomplete or even misleading, because it glosses over the importance of independent strategic choices made by individual firms. In particular, the claim that all private entrants 'mimicked the leader [Osaka Spinning]' in choosing the minimum efficient mill size and the right type of spinning machinery (Saxonhouse, 1974) is a clear example of hindsight bias. In fact, among 73 private firms newly established in the industry from 1887–1898, only 25 contained 9,500 or more spindles at the start of operations (see Braguinsky and Hounshell, 2015, Tables 3 and 6). Nineteen of those failed to ever reach this threshold as independent firms. The situation was similar with the choice of machine types.

This hindsight bias presumably came from the natural tendency by researchers to focus their attention on long-term industry survivors, something that a comprehensive nanoeconomic dataset allows us to avoid. Examining the choices made by all firms (including failed firms) is important if only because it clearly overturns the conclusion that 'Japanese industrialists slavishly imitated each other' and that, therefore, the most important decision-making level in the industry was that of the industry association (Boren) (Saxonhouse, 1974, p. 150; see also

Fletcher, 1996). In fact, the role of human capital possessed by individual firms was as crucial in providing the conditions for industry takeoff in the late 1880s and early 1890s as was the initial example set by Osaka Spinning Company in the mid-1880s. Moreover, as we show in the next section, the human capital differential that first manifested itself at this stage was subsequently the key factor determining firm survival during the industry's consolidation phase.

Several new early private entrants, working together with each other and in cooperation with Osaka Spinning Company and the Yamanobe-led revamped Boren, were instrumental in ushering in two major innovations that paved the way for explosive industry growth: the introduction of ring spinning frames and the development of new major sources of supply of longer-staple cotton, first from India and then also from the U.S. The former happened around 1887 when the just-appointed chief engineers of three firms founded in that year (Shunichi Hattori of Owari Spinning, Tsunezo Saito of Mie Spinning, and Kyozo Kikuchi of Hirano Spinning) were sent by their respective employers to England for training and to place orders for spinning machines. All three firms were clearly influenced by Osaka Spinning Company's previous experience with Yamanobe (in fact, Mie Spinning was a spinoff of Osaka Spinning Company; more on this below). Significantly, all three men were recent graduates of the Imperial College of Engineering (Tokyo) and thus were more qualified than Yamanobe had been earlier. The three more or less simultaneously decided to order ring spinning frames for their mills rather than mules, which had been the technology choice until that time (according to Tamagawa, 1997, they were also influenced by Senjiro Watanabe, Mitsui Trading's representative in London, through whom the orders were placed).[8] The subsequent speed of diffusion of ring spinning technology in Japan was the fastest in the world (Saxonhouse and Wright, 1984).

[8] Watanabe is perhaps another example of the critical role of markets-for-technology intermediaries in this story.

Roughly a year later, led by Yamanobe and his Osaka Spinning Company, Boren organized a mission to India to study the possibility of importing long-stapled Indian cotton to replace short-stapled Japanese and Chinese cotton, the reliance on which had put severe limitations in the way of improved productivity, performance, and range of products of Japanese mills. Experiments were conducted at Osaka's and Mie's premises, and in line with the tradition of knowledge-sharing established in the industry, Indian cotton samples were distributed to other firms. Boren also negotiated a discount on shipping costs for imported cotton as well as the elimination of the (fairly low) import tariff on raw cotton, which applied equally to all its members.

The almost simultaneous adoption of ring spinning technology and longer-stapled Indian (and shortly after U.S. long-stapled) raw cotton were the two most important factors that propelled the industry towards its success (see, e.g., Tamagawa, 1995). But not all firms adopted the new technologies, particularly longer-stapled cotton, at the same rate. The earliest firm-level data on different types of cotton inputs used by individual mills are available in *Geppo* for 1893. In that year, non-Japanese and non-Chinese sources of cotton accounted for about 50 percent of the total amount of raw cotton consumed by the industry, but there was a lot of variation across different mills (see Braguinsky and Hounshell, 2015, Figure 2).

It turns out that the degree of penetration of new types of cotton was strongly related at the firm level to its human capital (educated engineers at the helm). There were only 11 college-educated engineers employed by all firms in 1893, with two of them having received their training in areas other than cotton spinning engineering. These engineers, several of whom provided services to more than one employer, worked for 18 out of a total of 38 firms that operated in the industry in 1893 (18 survivors from the government-aided and 20 new entrants).

In the first two rows of Table 3 we present binary comparisons in cotton inputs between firms that were run or at least guided by trained engineers and all other firms. The first row shows the differences in means of the combined fraction of Indian and U.S. cotton in the total amount of raw cotton consumed by each category of mills. The second row shows the difference in the degree to which they engaged in cotton mixing. The latter was especially important because the technology of cotton staple blending qualifies as the first globally important innovation to emerge from the young Japanese industry and became one of the major sources of its international competitiveness (Saxonhouse and Wright, 2010). We constructed this measure ('cotton mixing index') as follows. We first assigned a dummy equal to 1 to each type of cotton if its usage in 1893 was 5 percent or more of the total quantity of cotton consumed by the mill and zero otherwise. We then added all these dummies together. For example, Osaka Spinning Company mill used 41.3 percent Chinese cotton and 54.3 percent Indian cotton in 1893, while other types constituted less than 5 percent of its total consumption, so its 'cotton mixing index' assumes the value of 2, and so on.

Table 3 shows that in 1893, the fraction of Indian and U.S. cotton employed by firms with college-educated engineers at the helm was more than double the same fraction in firms that did not have access to such engineers' services (the difference is highly statistically significant). Firms led by college-educated engineers also had on average 3.3 different types of cotton accounting for at least 5 percent of their total cotton consumption, compared to 2.5 types for all other firms (the difference is statistically significant at the 5 percent level).[9]

Differences in technological choices also affected firms' performance, as can be seen in the last two rows of Table 3 showing the differences in mean total factor productivity and mean

[9] Braguinsky (2015) provides more examples of how firms with superior engineering talent at the helm made better technological choices compared to other firms during those early years of rapid growth.

profitability between the same two categories of firms. Total factor productivity, once again, is measured as the residuals from estimating the production function as in equation (1) above (separate estimates of labor and capital productivity yield very similar results). For profitability, we utilize balance sheet data from the 1893–94 *Geppo* to create the 'return on assets' measure, which is the amount of profit (loss) reported by the firm, divided by the total value of all assets on its balance sheet. It can be seen that firms with college-educated engineers at the helm economically and statistically significantly outperformed all other firms in terms of both productivity and profitability of their operations.

[Table 3 around here]

The importance of 'discretionary differences' across firms can also be seen by examining the response (or lack thereof) of government-aided firms that had started operating prior to the mid-1880s to innovations introduced by Osaka Spinning and other early private entrants. In the online appendix, we present basic data that show the dynamics of the introduction of organizational and technological innovations by each of those 20 older mills over the 12-year period, from 1884–1896. While all mills were similar to each other in 1884 (Table A1 in the online appendix), by 1896 11 out of 16 surviving firms were joint stock companies, and many mills had exceeded the minimum-efficient scale and modernized their machine stock (Table A4 in the online appendix). Table 4 summarizes the changes that occurred over the whole sample. Five firms increased their capacity at similar or even higher rates than Osaka Spinning Company did, and they all went through the incorporation process in the first few years (Table 2A in the online appendix). Two of those (Mie and Shimotsuke) constructed new 'centrally located' mills (mills located in or close to a major commercial city), whereas they had been previously located in remote areas (the other three firms, Okayama, Tamashima, and Nagoya, were centrally located to begin with). All of these reorganized firms adopted steam engines and replaced almost all their older mules by ring spinning frames. On the other end, five firms failed to incorporate, and none was able to accomplish any expansion or technological modernization.

[Table 4 around here]

Even though incorporation appears to be a necessary condition for the revival and growth of former government-sponsored mills, it was not sufficient. For instance, Enshu Spinning and Miyagi Spinning had been joint stock companies since founding and nevertheless neither made changes to their technologies nor expanded their capacities over the whole sample period. Early incorporation (and ownership change) did nothing in terms of technology or firm size for several other firms either (see Tables A1–A4 in the online appendix). It appears that incorporation helped the process of modernization only if it entailed participation by prominent investors with national profiles.

As noted, the most successful former government-aided mill, Mie Spinning, received so much direct assistance from Eiichi Shibusawa (founder of Osaka Spinning), that it can be called its spinoff. This mill, originally founded in 1880 as one of the government-sponsored 2,000-spindle mills in a remote village in Mie prefecture in Central Japan, had been totally undistinguished during its government-aided period. In 1886, however, the owner of the mill had a chance to seek Shibusawa's advice. Shibusawa recommended incorporation and construction of a new 10,000-spindle mill operated by a steam engine in the commercial center of Yokkaichi. He also invested half of the required new capital. Furthermore, Shibusawa also recommended a graduate of the Imperial College of Engineering, Tsunezo Saito, as the new chief engineer. Once hired, Saito was immediately sent by the company to study cotton spinning in England—an action probably also taken at Shibusawa's or Yamanobe's urging.

While Mie Spinning's case is the most conspicuous one, three more former government-aided mills were able to attract support from prominent investors. Shibutani mill was purchased in 1885 from the previous owner by Jutaro Matsumoto (Shibusawa's partner and CEO of Osaka Spinning at the time). He turned it into a joint stock firm, Dojima Spinning Company, and hired Osaka Spinning's Takeo Yamanobe as the firm's technology advisor. Shimotsuke mill recruited Tanizo Kakinuma, a cotton merchant from Tokyo and one of the former advisors to Shibusawa at Osaka Spinning. Kakinuma helped with Shimotsuke Spinning's incorporation and then temporarily took over as the firm's president. Finally, Tamashima mill's owner encountered Takejiro Kunitake, a wealthy investor from Japan's southernmost island of Kyushu in 1884 during his visit to Osaka. Already looking for an opportunity to invest in the cotton spinning industry, Kunitake helped incorporate Tamashima Spinning by providing his own capital and bringing more investors. He also helped to arrange for Shinichiro Arakawa (a college-educated engineer working for the government at the time) to become the company's technical advisor.

To measure the effects of incorporation and especially incorporation accompanied by participation by prominent national investors, we estimate the following regression using comprehensive panel data for years 1884–1897 on all 20 firms founded before 1886 (excluding Osaka Spinning Company):

$$dlogcap_{it} = \alpha + \beta_1 incorp_{it-1} + \beta_2 prominv_{it} + \beta_3 logmachineage_{it-1} + \mu_t + \eta_i + \epsilon_{it}, \qquad (2)$$

where the dependent variable is the difference between the (logged) number of spindles installed in firm *i* in year *t*, and the (logged) number of spindles installed in firm *i* in year *t*-1 (a measure of the firm capacity growth rate). The variable $incorp_{it-1}$ is the dummy equal to 1 if the firm was incorporated in year *t*-1 and 0 otherwise, while the variable $prominv_{it}$ is the dummy equal to one for the first five years after incorporation in case a nationally prominent investor participated in the newly incorporated entity, and zero otherwise. The controls include $logmachineage_{it\text{-}1}$, the logged vintage-adjusted age of machines of firm i in year t-1, firm fixed-effects η_i, and year fixed-effects, μ_t, to control for overall economic conditions.

The results of estimating regression (2) in three different specifications are presented in Table 5. In the first specification, only the $incorp_{it\text{-}1}$ variable is included, in the second one, only the $prominv_{it}$ variable is estimated, while the third specification includes both variables. The estimated coefficient β_1 on the lagged incorporated status in column 1 indicates that successful incorporation was associated with about 12.5 percent faster growth rate of firm capacity on average, statistically marginally significant. The estimated coefficient β_2 in the second column capturing the effect of the presence of a nationally prominent investor, on the other hand, is almost 2.5 times larger in magnitude and statistically highly significant. Moreover, it remains almost the same in the third column where both variables are included at the same time, while the coefficient on incorporated status is halved in magnitude compared to column one, and statistically is no longer significant at conventional levels.

[Table 5 around here]

Unquestionably, the prominent investor effect has a lot to do with selection, although not necessarily on mill attributes. Selection on mill attributes was most clearly pronounced in the case of Dojima Spinning, where Jutaro Matsumoto’s purchase had to do with its location and steam technology already employed by the previous owner. The same attributes perhaps made Tamashima Spinning an attractive investment opportunity for Kunitake, although his encounter with its previous ownership appears to have been accidental. But the attributes of mills’ ownership (that is, self-selection) were also important. In the other two cases (Mie Spinning and

Shimotsuke Spinning), there were no particularly attractive attributes to the mills themselves, but the owners actively sought outside investors' help. Such efforts were not always successful, however. For example, in 1886, the chief executive of Enshu Spinning also announced, to great fanfare, a project to build a new 10,000-spindle steam-powered mill in the commercial city of Hamamatsu (exactly the same plan as the one that propelled Mie Spinning to success). The project attracted investors, including prominent investors from Tokyo who helped quickly raise almost half of the required new capital. However, Enshu Spinning had already been a joint stock company, and in an ironic twist, the plan died in less than a year because of opposition from minority shareholders (mostly small capitalists from local villages) who did not want to give up control of the venture (Takeyama, 2008, pp. 375–77).

Technological deepening and asset reallocation: Adapting to market environment change

The organizational and technological breakthroughs of the late 1880s amounted to 'refinements' or 'dominant design' events in the life cycle of the Japanese cotton spinning industry. Domestic output jumped by almost 3 times in 1889 alone and increased by more than 10 times in the following decade (Figure A1 in the online appendix). Imports of cotton yarns rapidly became an afterthought, while exports took off and surpassed imports in 1897.

As is typical in an industry's life-cycle (Gort and Klepper, 1982; Agarwal and Gort, 1996), this growth was driven largely by new entry. While only 2 new firms were founded in 1890–91, 22 more mills came into existence in 1892–94 (including two founded in the 1880s but that had produced only cotton cloth until the early 1890s), followed by 27 more in 1895–1898. The driving force was rapid diffusion of best practices, as new entrants took advantage of innovations pioneered by early leaders. At the peak of output expansion around 1895–97, these new entrants appeared to surpass the latter in terms of productivity (see below).

Nevertheless, once the industry entered the shake-out (consolidation) phase at the turn of the last century, it was early private entrants that (re-)emerged as the undisputed industry leaders. In this section we use combined plant-, firm-, and market-level data to tease out the most important factors behind the shakeout and reorganization of the industry. Specifically, we use these data to measure the impact that asset reallocation had on the productivity and profitability of individual firms and the efficiency with which the industry as a whole operated.

As mentioned earlier, at the dawn of the industry, Yamanobe had worked with Platt Brothers' engineers to adapt their machines to Japanese short-stapled cotton. This, in particular, involved slowing down the rotation speed of the spindles to limit thread breakages. Transition to longer-stapled cotton imported from India and the U.S. rendered such adaptation unnecessary. Figure A2 in the online appendix shows that spindle rotation speeds of machines ordered by Japanese mills increased on average by 14 percent (from 7,200 rpm to 8,200 rpm) between 1887–89 and 1899–1901. Notably, the figure shows no increase in the speeds of machines ordered by the UK or Indian mills over the same period, so the increase in the speed of machines ordered by Japanese mills reflected their catch-up to the technological frontier. As new entrants were ordering machines for the first time in the second half of the 1890s, they were able to make the most of such opportunities. As a result, at the turn of the 20th century, the machines installed by new Japanese entrants were not just faster (potentially increasing capital productivity) than many of those still installed in the production facilities of older firms, but also had more spindles per frame (potentially increasing both capital and labor productivity), were more versatile (designed to work with several types of cotton, making it easier to develop cotton blending technology) and were capable of spinning yarn of finer counts (higher quality) (see Braguinsky et al., 2015, Tables A3 and A4). These new and improved machines made newer entrants potentially more productive than even early industry leaders.

In Table 6 we compare the 'total factor productivity' of older firms and newer entrants by estimating a standard production function regression, using monthly data on outputs in physical units (adjusted to the standard 20^{th} count) and capital and labor inputs (measured in spindle-hours and work-hours), controlling also for year and month fixed effects, for years 1895–97 (the final three years before the start of the shake-out phase). The 'new entrant' variable is a dummy equal to 1 if the firm entered the industry in 1892 or later, and zero otherwise (choosing other reasonable cutoffs yields similar results); the 'early leader' variable is a dummy equal to 1 if a firm, founded before 1892, had already reached the capacity of at least 20,000 spindles on average during 1895–97, and zero otherwise (in fact all the firms meeting these criteria had been founded prior to 1890). The estimated coefficients on each of these dummies capture how much more or less productive new entrants and early industry leaders, respectively, were compared to the omitted category (all other firms founded before 1892). We can see that new entrants outperformed older firms by about 13 percent [exp(0.124)–1], while the advantage of early leaders is less than 9 percent. Both coefficients are statistically highly significant, and the difference between estimated coefficients on the 'new entrant' and 'early leader' dummies is also statistically highly significant.

[Table 6 around here]

Output expansion and new entry changed the market environment. As can be seen in Figure A1 in the online appendix, during the first half of the 1890s, Japan was still considerably dependent on imported cotton yarn. This means that Japanese mills did not have to worry about demand. Once the share of imports fell below single digits by 1897, the days of an infinitely elastic demand ready to absorb domestic production were gone. Burgeoning exports to China pushed the day of reckoning down the road by a few years, but when the Boxer Rebellion temporarily closed the Chinese market, market size finally had to be reckoned with.

Consolidation ensued. Total output growth slowed down, and exports remained flat (Figure A3 in online appendix). At the firm level, there was almost no new entry, but there were plenty of exits. Among 85 firms that operated in 1897–99, only 21 survived until 1912. Among the 64 firms that exited, however, only 13 shut down their mills (typically outdated mills from the government-aided era). The remaining 51 mills were acquired and continued operating (in most cases without interruption). Significantly, 36 of these were post-1892 entrants (70 percent of all those entrants were acquired as opposed to less than 40 percent of earlier entrants). Thus, the productivity advantage of new entrants (their higher-quality machines) did not translate into better survival, although it did translate into higher rates of being acquired by other firms.

In almost half of acquisition cases (22), the acquiring firm was one of the 5 early industry leaders (Osaka, Mie, Kanegafuchi, Hirano, and Settsu) that had entered before 1890 and played a pioneering role in the industry's innovations of the 1890s.[10] Figure A4 in the online appendix shows the concentration of ownership in those firms. Together, they accounted for less than 10 percent of all plants and less than 30 percent of industry-wide capacity and output in the late 19th century. By 1912, their share of the number of plants had increased to 40 percent, and they accounted for 50 percent of the industry's capacity and output.

One might conjecture that mass exit by newer entrants through acquisitions by early industry leaders could have been driven by factors other than efficiency in the production process, such as market power. Our nanoeconomic data set, distinguishing between firm-level

[10] Hirano Spinning itself was acquired in 1902 by Settsu Spinning, in what is a very instructive case discussed in some detail below.

and production establishment-level variables and containing also information on market structure as well as on individuals in charge of various firms, allows us to scrutinize this conjecture.

At the time, Japanese cotton yarn producers faced a competitive market, with most of the spun yarn purchased and distributed by large trading houses, such that not even the largest firms could exercise much price-setting power (Takamura, 1971, Vol. 2). Instead, what differentiated the largest and most successful firms from other firms was operational efficiency. In Table 7 we present evidence pertaining specifically to the years 1898–1900—that is, prior to most acquisition events. We compare the profitability of five leading acquiring firms mentioned above and the firms that would be acquired by them (most, although not all, second-wave entrants). We also show how some other measures associated with profitability differ across these two categories.

[Table 7 about here]

As can be seen from Table 7, despite demand difficulties that were already strongly pronounced in this period, leading acquirers managed to achieve on average almost 7 percent return on capital employed, while firms that would be acquired by them had an average return of only 1.2 percent (20 of those firms had negative profits in at least one year). The differences in profitability were not, however, driven by the 'usual suspects,' such as productivity or prices; Table 7 shows no economically or statistically significant differences along those dimensions. Instead, the two aspects of their operations that were economically and statistically different were the number of days in operation and the ratio of the value of unrealized to produced output. (The unrealized output is defined as the sum of unsold yarn on the company's balance sheet, plus the amount of accounts accruable.) These two variables are closely related to each other, as both reflect the firms' ability to continue selling output even under adverse conditions.

Nanoeconomic data allow us to look into the sources of this advantage in more detail. The most important such source was close attention paid to strategic management right from the beginning. This attention manifested itself in various ways for different firms, but one common thread was understanding of the importance of managing the vagaries of the demand, ensuring product quality, and diversifying the product mix.

Demand management was important because during downturns, established trading houses tended to limit their purchases from all but the most reputable producers, with which they had valuable long-term relationships (see, for example, Takamura, 1971, Vol. 2). Other firms were left to scramble to find buyers, leading to build-up of unwanted inventories (and/or payment arrears) and increased stoppages. We used archival data to match top shareholders' and executives' names of cotton spinning firms to the names of executives of large incorporated cotton yarn trading houses, as well as of the largest individual traders. More profitable firms (and notably, all the early industry leaders among them) were deeply immersed in those trader networks, while many new entrants were not. Significantly, this immersion was not something that industry leaders acquired over time and so was not part of the 'first-mover advantage.' Instead, prominent cotton traders were associated with industry-leading firms *already at their founding*, long before marketing and demand management became a major issue. This early strategic action clearly separated pioneers from later imitators.

Attention to product quality during those early years of industry development meant first and foremost having competent, trained engineers in charge of production facilities (for example, we already saw in Table 3 above how important they were in the adoption of higher-quality Indian and U.S. raw cotton). Tables A6 and A7 in the online appendix show that 14 out of 23 early private entrants (founded from 1887–91) employed college-educated engineers, including those in advisory role. In contrast, out of 49 second-wave entrants (founded from 1892–98), only 7 had college-educated engineers in charge (and 5 more had access to advice by such engineers employed by other firms). The most prominent future acquirers had the best of the young Japanese engineering and managerial corps—Yamanobe at Osaka Spinning, Saito at Mie Spinning, Kikuchi at both Hirano and Settsu (as well as Amagasaki) Spinning, and Sanji Muto at Kanegafuchi Spinning. The latter was also the only manager who was not an engineer (even though Kanegafuchi was originally set up under the guidance of Naosada Taniguchi, who had Ph.D. in mechanical engineering), but Muto was a representative of a new generation of Japanese managers, with experience working in the U.S.

Product diversification and willingness to experiment were other factors that set industry leaders apart from other firms early on. Thus, Yamanobe's first (even though not quite successful at the time) experiment with downstream integration into weaving dates back to 1887 (Toyo Boseki, 1986, Vol. I, p. 60).[11] In 1903 (the earliest available comprehensive data) only three spinning firms had more than 1,000 mechanical looms installed (*Sankosho*, 1903, pp. 1–5). Two of them were Osaka and Mie Spinning, while the third one was Nihon Spinning, set up in 1894 by a large consortium of investors, most of whom had already invested in other leading firms, with the explicit aim to experiment with high-count yarns and power looms. Around the same time, Kikuchi started developing the production system for high-quality 42nd count and gassed yarn at Amagasaki Spinning (Kinugawa, 1964, vol. III). Such downstream integration and product-line broadening and experimentation resonates with findings highlighted in strategic management literature that better firms develop capacities far beyond what is necessary just to survive in a given environment (see, e.g., Brusoni, Prencipe and Pavitt, 2001). Strategic anticipation of future developments kept early private entrants in the leading positions during

[11] Notably, Yamanobe also got this idea from conversations in England during his study there (Toyo Boseki, 1986).

and beyond the industry's consolidation phase, allowing them to increase their 'span of control' at the expense of weaker firms.

In the end, superior strategic management of the leading firms manifested itself not only in higher profitability and operational efficiency but also in better physical productivity of the establishments they acquired from other firms. As can be seen from examining Figure A5 in the online appendix (the estimations leading to which are also presented and explained therein), acquisitions by one of the five leading firms improved the physical productivity of acquired mills, *conditional on operating*, by 15 percent in the first three years and by 10–15 more percentage points in subsequent years (since acquisitions also improved capacity utilization rates, the improvement is even larger if increased capacity utilization is taken into account). This suggests that superior physical productivity of second-wave entrants in the late 1890s (see Table 6 above) as well as the lack of productivity differences between future acquired and acquiring firms in Table 7 can be attributed to the difference in machines vintages; the later vintages available to later entrants (many of them future acquired firms) made their production facilities inherently better than those of leading acquirers. But these newer machines had been employed relatively *inefficiently* prior to being acquired as compared to following acquisition. We have here one more indicator that the strength of industry-leading firms did not come just from market power but was rooted in their superiority in managing productive assets.

One more thing about the experience of the Japanese cotton spinning industry that needs to be emphasized is the importance of the right institutional and market conditions. We already noted the role played by the government's abandoning its bureaucratic control and practice of dishing out subsidies to politically selected entrepreneurs. Also, acquisitions that improved the productivity of failing firms' plants could not have happened without most firms being organized as joint stock companies with easily transferrable shares. In fact, recent studies of the Indian textile industry have suggested that lack of ownership transfer mechanisms remains one of the major stumbling blocks to improved efficiency in developing countries even today (see Bloom, Eifert, Mahajan, McKenzie, and Roberts, 2013).

Another institutional feature that spurred the Japanese cotton spinning industry was competitive conditions not only in input, output, and production facilities markets but also in the market for talent. Two of the best early engineers, Yamanobe of Osaka Spinning and Saito of Mie Spinning, stayed with their original employers for their whole careers. But they were exceptions rather than the rule. A more typical example seems to be that of Kyozo Kikuchi, initially with Hirano Spinning Company. Despite his talent, he was bypassed for promotion to an executive because he was not a wealthy man. However, Settsu Spinning, a company Kikuchi was advising, elected him to its board in 1897, prompting him to resign from Hirano Spinning. Hirano soon began to decline and was acquired by no other than Settsu Spinning just 5 years later, in 1902. Meanwhile, Amagasaki Spinning also promoted Kikuchi to an executive position, and then elected him president of the company in 1901. In rebuking the opposition to Kikuchi's board nomination, Amagasaki's president reportedly remarked that 'Kikuchi's talent is a far more important asset for us than any money he could possibly have.' (Kinugawa, 1964, Vol. III) Kikuchi ended up commanding both firms, eventually merging them in 1918 to create Dainippon Spinning (which still survives under the name of Unitika).

Discussion: Some general lessons for the nanoeconomic approach in strategy research

Japan's success story is still sometimes presented as an instance of government-sponsored industrialization, or at least one where identifiable government policies targeted at a specific industry were vital or at least very helpful (see Rodrik, 2014, for a most recent example of such an argument). A closer, nanoeconomic examination reveals, however, that the growth of cotton textiles in Japan was spearheaded by a firm that received no government sponsorship and deviated radically from government-advocated technologies. Innovations developed by this firm, together with other successful early *independent* entrants clearly inspired by its example, laid the foundation for industry-wide best practices. Through a collaborative institution in the form of an industry association, the information and know-how about these best practices and the market infrastructure needed to utilize them were available to all industry participants, including new entrants. Nevertheless, the story of almost seamless diffusion based on this institutional arrangement (see Saxonhouse, 1974) is not quite true either. Using detailed nanoeconomic evidence, we show that only a select subset of firms (mostly the successful early movers) were able to fully adopt the best practices and to survive the subsequent shake out.

The actual story appears to be that of several leading private entrants, powered by visionary entrepreneurs and guided by the first generation of educated engineers whose technical knowledge stemmed from direct contacts with state-of-the art sources in England. These investments broke the spell of backwardness and put the Japanese cotton spinning industry on the path to global competitiveness. As pointed out by Mass and Lazonick (1990), these were the key factors that distinguished the Japanese industry from its counterparts in India and China that also had access to cheap labor. Furthermore, while favorable institutional and market conditions were indispensable, the story of the evolution of the industry would be woefully incomplete without fully embracing the role played by the outliers. At least two major industry changes (the shift from small-scale technologically backward mills to large-scale enterprise in the late 1880s, and the new technological paradigm of blending imported long-stapled cotton and employing ring spinning frames in the 1890s) derived from their far-reaching strategic choices. The evolution of many other industries, from the U.S. auto and semiconductor industries (Tilton, 1971; Klepper, 2002) to the personal computer industry (Isaacson, 2011) and Bangladesh's garment industry (Mostafa and Klepper, 2011), also cannot be meaningfully understood without similarly delving deeply into the thoughts and actions of exceptional firms and individuals from which their ascendance began.

Important decisions that propelled industry-leading firms to success encompassed all aspects of strategic management, not just technology. Equally important were early decisions to establish vital commercial networks, both domestically and in the export markets, to undertake early experiments with differentiated products, and to pursue downstream integration at the time when the market environment seemed to favor simply ramping up existing output capacity. When the shakeout phase arrived, triggered by an exogenous demand change, these investments played key roles in not just keeping early innovators at the industry helm but allowing them to acquire and revamp production facilities of more myopic, weaker firms.

It is sobering to know that, at the dawn of the industry, the worst kind of technological choices were made by firms that received not just government subsidies but also government technical assistance. This finding, made possible by creating a detailed nanoecomomic dataset, should finally put to rest the view that Japanese government efforts played a vital role in steering the industry in the right direction. While there are cases of successes in such government-led endeavors (e.g., the semiconductor industry in Taiwan), 'The vast majority of efforts by the public sector to target particular industries seem to have been far less successful.' (Lerner, 2009, p. 132)

Our findings also call attention to the importance of avoiding hindsight bias coming from looking only at outcomes of ultimate survivors and represented by contention that all technological choices of firms that entered after the end of government support for the industry were uniform. In fact, as we showed here, there was a lot of 'discretionary heterogeneity' among firms entering long after the establishment of Osaka Spinning and other pioneering firms. This heterogeneity eventually converged to the winning combination of technological and managerial solutions through industry-leading firms leveraging their superiority in strategic management to extend their 'span of control' over production facilities of firms that were forced to exit by market competition. The leaders could do that, in part, because their top managers had invested in developing demand and sales networks, improving quality, diversifying and upgrading the product mix, and so on.

Perhaps the most surprising takeaway from our study of the Japanese Meiji-era cotton spinning industry is that individual vision and volition mattered so much. A certain cognitive stereotype makes Japan one of the countries from which a researcher least expects such a finding. In fact, however, the cotton spinning industry is just one among many Japanese industries that cannot be imagined in their present state without great individual innovators creating great companies basically from scratch, often in the face of untenable choices made within government bureaucracy.

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Table 1. Technology choices of government-owned and subsidized mills guided and not guided by Ishikawa in 1883–86.

Means of:	Guided by Ishikawa	Not guided by Ishikawa	
Size (number of spindles	2,196	2,200	
Powered by water engines	0.70	0.26	***
Capital to labor ratio	38.60	32.38	***
Female to male operatives ratio	2.60	1.96	***

Note: *** indicates that the difference in means is statistically significant at the 1 percent level, using a double-sided *t*-test with unequal variance. *Source*: our calculations based on data sources described in the online appendix.

Table 2. Productivity of government-owned and subsidized firms guided and not guided by Ishikawa in 1883–86.

		Logged labor productivity	Logged capital productivity	Total factor productivity
Guided by Ishikawa dummy	Coefficient	-0.098 **	-0.288 ***	-0.169 ***
	St. Error	0.042	0.044	0.037
Constant	Coefficient	3.315 ***	-3.303 ***	0.113 ***
	St. Error	0.038	0.036	0.029
Year-month dummies		Included		
Observations		370	371	370
Adj. R-squared		0.227	0.406	-0.029

Note: The total number of firms is 19, 12 of them supervised by Ishikawa and 7 not supervised. Available monthly data on firm operations for years 1883–1886 (32 months total). Labor productivity is calculated as monthly output (in weight units), divided by total number of worker-days employed; capital productivity is calculated as monthly output (in weight units), divided by the total number of spindle-days in operation. Multifactor productivity is calculated as the residual from the production function estimated by OLS with logged output as the dependent variable, and logged spindle-days in operation, logged worker-days employed and year-month dummies as independent variables. *** and ** indicate that the corresponding coefficients are statistically significant at the 1 and 5 percent level, respectively. *Source*: our estimates.

Table 3. Human capital, cotton mixing, and firm outcomes, 1893.

Mill guided by:	College-educated engineer	Non-college educated engineer	
Fraction of Indian and U.S. cotton in total	0.458	0.210	***
Cotton mixing index	3.278	2.500	**
Mean total factor productivity	0.074	-0.079	***
Mean ROA (1893-1894)	0.132	0.108	*

Note: Total factor productivity measure is the average residuals from estimating the production function as in (1) in the main text. ROA is return on assets, firms' reported profits divided over the value of total assets in the balance sheet. ***, **, and * indicate that the corresponding difference is statistically significant at the 1 percent, 5 percent, and 10 percent levels, respectively, using double-sided *t*-test. *Source*: our calculations based on data sources described in the online appendix.

Table 4. Within-firm changes, 1884–1896.

Firm name	Firm capacity (# of spindles) ratio	Change in machinery age	Change in fraction newer vintage	Was or switched to steam power	Was or became joint stock company	Centrally located or constructed a centrally located plant
Osaka	5.28	3.80	1.000	Yes	Yes	Yes
Aichi	1.00	12.00	0.000	Yes	No	No
Ichikawa	1.00	12.00	0.000	No	No	No
Okayama	13.96	1.80	1.000	Yes	Yes	Yes
Kagoshima	1.00	12.00	0.000	Yes	No	No
Kuwanohara	1.00	12.00	0.000	No	Yes	No
Shimada	0.85	0.70	1.000	No	No	No
Shimotsuke	4.97	-1.00	0.799	Yes	Yes	Yes
Enshu	1.00	11.0	0.000	No	Yes	No
Shimomura	2.28	1.20	1.000	Yes	Yes	Yes
Tamashima	12.57	2.60	1.000	Yes	Yes	Yes
Nagoya	4.51	5.00	0.556	Yes	Yes	Yes
Himeji	2.06	3.00	1.000	Yes	Yes	No
Hiroshima	1.25	10.00	0.178	Yes	Yes	No
Toyoi	1.00	12.00	0.000	Yes	No	No
Mie	25.70	1.56	0.770	Yes	Yes	Yes
Miyagi	1.00	12.00	0.000	No	Yes	No

Note: Firm capacity ratio is the number of installed spindles in 1896 divided by the same number in 1884. Change in machinery age is the vintage-adjusted age of machinery in 1896, minus the same in 1884. Change in fraction of new vintage is the fraction of newer ring spinning frames in total capacity in 1896 (uniformly zero for all firms back in 1884). 'Centrally located' means located in or close to a major commercial city; otherwise, the location is in a remote area far from major markets. Enshu Spinning started operating in 1885, so its data cover the period from 1885-1896. *Source*: our calculations based on data sources described in the online appendix.

Table 5. Organizational change and capacity expansion, 1884–1896.

	Specification		
Variables	(1)	(2)	(3)
One-year lagged incorporated status dummy	0.118* (0.067)		0.051 (0.054)
Prominent investor dummy		0.290*** (0.040)	0.275*** (0.043)
Logged one-year lagged machinery age	0.127*** (0.044)	0.133*** (0.041)	0.138*** (0.043)
Year dummies	Yes	Yes	Yes
Firm dummies	Yes	Yes	Yes
Constant	-0.366*** (0.128)	-0.299*** (0.103)	-0.153** (0.064)
Observations	242	242	242
Adj. R-squared	0.161	0.232	0.231

Note: The dependent variable is the difference in logged firm capacity (number of spindles installed) from the previous year. Robust standard errors clustered at firm level in parentheses. ***, **, and * indicate statistical significance at the 1, 5, and 10 percent levels, respectively. 'Prominent investor dummy' is equal to 1 for the first full 5 years after the firm established relationship with nationally prominent investors. *Source*: our calculations based on data sources described in the online appendix.

Table 6. Productivity of new entrants and older firms in 1895–97.

Variables	Dependent variable: (Logged) output adjusted to 20th count
Logged number of spindle-hours	0.684*** (0.023)
Logged number of work-hours	0.370*** (0.023)
New entrant	0.124*** (0.013)
Early leader	0.082*** (0.016)
Constant	-5.189*** (0.134)
Year and month dummies	Yes
Observations	1765
Adj. R-squared	0.966

Note: new entrants are firms founded in 1892 or after. Pooled OLS over years 1895-1897 using monthly input-output data. Robust standard errors in parentheses. *** indicates that the coefficients are statistically significant at the 1 percent level. Early leaders are 13 firms founded before 1892 that had reached average capacity in excess of 20,000 spindles by 1895–97. *Source*: our calculations based on data sources described in the online appendix.

Table 7. Return on capital and factors behind it: future acquired firms and leading acquirers in 1898–1900.

Variables: means of	Leading acquirers	Future acquired	Statistical significance
Return on capital employed	0.069 (0.014)	0.012 (0.011)	***
TFP (relative to industry-year average)	0.015 (0.035)	-0.008 (0.023)	
Main count of yarn produced	19.1 (1.4)	22.1 (1.9)	
Unadjusted output price (per unit weight)	97.4 (3.6)	98.6 (6.2)	
Count-adjusted output price (per unit length)	107.9 (5.5)	100.5 (2.6)	
Days in operation (per year)	321.0 (2.23)	302.2 (6.91)	**
Unrealized output to produced output ratio	0.057 (0.007)	0.119 (0.014)	***

Note: Standard errors in parentheses. Leading acquiring firms are Osaka, Mie, Amagasaki, Settsu, and Kanegafuchi Spinning, as explained in the main text. All variables are measured as averages over three years, from 1898–1900. Return on capital invested is the ratio of reported company profits (before taxes and dividends) to the sum of shareholders' equity, borrowings, bonds, and interest-bearing promissory notes. Inventory to output ratio is the ratio of the sum of year-end book values of unsold yarn and accounts receivable to the value of output produced during the year. TFP (total factor productivity) is the residual from production function estimation using observations on all firms and all years, including year dummies (hence, it measures TFP of a given firm relative to industry-year average). Count-adjusted output price is price per unit weight, multiplied by the standard 20th count and then divided by the actual count produced. *** and ** indicate that the difference between the means in two columns is statistically significant at the 1 and 5 percent levels, respectively, using a double-sided *t*-test with unequal variances. *Source*: our calculations based on data sources described in the online appendix.