Why Japan, Not China, Was the First to Develop in East Asia: Lessons from Sericulture, 1850–1937*

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Although Japan and China are geographically and culturally close, today their levels of economic development are worlds apart. The origin of this gap is relatively recent. As late as the nineteenth and early twentieth centuries, Japanese exports competed directly with Chinese in the international market in such low value-added, labor-intensive products as raw silk. Between 1850 and 1930, raw silk ranked as the leading export for both countries, accounting for 20%–40% of Japan's total exports and 20%–30% of China's.[1]

Raw silk consists of bundles of long, continuous silk threads used for silk weaving. Its production starts with sericulture that involves the cultivation of mulberry trees and the harvesting of the leaves to feed the silkworms that develop into self-spun cocoons. Traditionally, cocoons were hand-reeled into raw silk within rural households. However, by the latter part of the nineteenth century, the spread of mechanization was steadily shifting the reeling process to modern factories.

The performance of the Japanese raw silk exports contrasted sharply with that of China. In 1873 China exported three times as much raw silk as Japan, but by 1905, Japanese raw silk exports exceeded the Chinese, and in 1930, Japanese raw silk exports tripled those of China, gaining a dominant 80% share in the global market.[2] This contrast is puzzling given that as late as the sixteenth and seventeenth centuries, Chinese raw silk dominated the Japanese market, and even in the mid-nineteenth century, Chinese silk enjoyed a more favorable global reputation than that of Japan.

This article presents a comparative analysis of this dramatic contrast by focusing on the cocoon sector that contributes between 60% and 80% in the value added of raw silk, leaving the reeling sector to future study.[3] It also adopts a regional approach by comparing Japan with the Lower Yangzi, the most advanced region of China. They are comparable in size, population, and

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climate and are part of the wet-rice economies characterized by intensive agriculture, high population density, and small-scale farming. The broad similarities in initial conditions, factor endowment ratios, crop choice, and geographic environment offer us a rare case study of a relatively controlled experiment.[4]

I argue that the Japanese success in silk export largely derived from the capacity of its sericultural sector to develop appropriate technology and institutions through a creative combination of traditional technology and modern science to overcome its resource constraints. These accord well with the so-called induced innovation hypothesis advocated by Yujiro Hayami to explain the overall success of Japanese agriculture for the same period.[5] Thus, the absence of the Japanese style of innovation was the cause of the stagnancy of the Lower Yangzi sericulture.

Why did broadly similar conditions induce innovations in one place and not the other? I argue that important physical and social infrastructure built up after the Meiji reform in Japan but largely ignored by the Qing bureaucrats of the conservative Self-Strengthening Movement in the Lower Yangzi during the latter part of the nineteenth century are the key to understanding this contrast. This article shows further that the Japanese success in turn profoundly affected the Lower Yangzi and elicited a dynamic technological and institutional response in the 1930s when a minimal set of necessary conditions was gradually being put into place since the Meiji-inspired Late-Qing reform in 1903–11.

This article mobilizes a multitude of independent sources of information, including the voluminous survey reports on the Chinese silk sector written by Japanese specialists between the 1890s and the 1930s, and offers various technical and productivity indices, including a price dual total factor productivity (TFP) index. The quantitative analysis is further supported by a careful examination of the institutional and technological developments in the cocoon production and distribution sectors in these two regions.

The rest of the article is divided into three sections followed by a conclusion. Section I presents comparative data on output, input, and prices and estimates of partial and total factor productivities. Section II, consisting of three parts, offers a comparative narrative of technology and commercialization and a summary of growth accounting results. Section III describes the 1930s catch-up in the Lower Yangzi.

I. Output, Prices, and Productivity

Annual Japanese cocoon output (for both domestic consumption and export) almost quintupled from the 1890s to the 1930s to about 300,000 tons. Comparable data were not available for the Lower Yangzi. Robert Eng's collection of various French and Japanese scholars' cocoon output estimates gave a range of between 70,000 and 100,000 metric tons, with growth rates largely stagnant for the Lower Yangzi between 1875 and 1930. Despite the data problem, it seems plausible that the cocoon output performance largely mirrors the regions' contrasting performance in raw silk exports, that is, that circa 1930, Japan was producing three to four times more cocoons than the Lower Yangzi.[6]

Various household and land productivity data seem to confirm a similar story of contrasting performance between 1890 and 1929. Annual cocoon output per household in the late 1920s Lower Yangzi was about 50–65 kilograms, about a third of the Japanese level during the same period, but roughly equivalent to its 1900 level. Annual cocoon output per acre of land in the Lower Yangzi was estimated to be about 150 and 142 kilograms in 1897 and 1932, respectively, about 70% of the Japanese level in the 1920s but equal to the Japanese level around 1910. The actual cocoon productivities in the Lower Yangzi would be even lower in comparison to Japan if cocoon quality deterioration in the 1910s and 1920s were taken into account.[7]

These partial productivity indices suffer various shortcomings. For the Lower Yangzi, most estimates were based on scattered individual observations. For Japan, as will be shown later, land and labor productivity improvements were exaggerated by the rapid intensification in Japanese sericulture that occurred between 1900 and 1920. These problems posed formidable obstacles to the construction of TFP based on the primal input-output approach.

In this context, the cost (or price) based TFP approach is more viable as time series data of input and output prices were relatively consistent and reliable. The dual equivalence of production and cost side TFP based on a Cobb-Douglas production function requires the assumption of constant returns to scale and long run competitive market assumptions (with cost side TFP expressed as $A_t^d = \prod_{i=1}^{4} w_{it}^{\alpha_i} / AC_t$, w_{it} and α_i being price and weight, respectively, for the ith input at time t, AC_t as average cost of production and $\Sigma\alpha_i = 1$). Both these assumptions are reasonably satisfied for the small-scale and scattered rural sericultural production taking raw silk and cocoon prices as given by the global market.

To calculate the dual TFP, I have used cocoon price for *AC* and four price series of input, namely, labor, land, sericultural inputs (fertilizer, silkworm egg seeds, etc.), and capital (silkworm rearing room, tools) for the period between 1903 and 1928. Their summary statistics are presented in the appendix.

Figure 1 shows the annual cocoon (as well as raw silk) prices for Japan and the Lower Yangzi all converted into Japanese yen. The cocoon price of the Lower Yangzi is from Wuxi, the most important cocoon-marketing center in the region. Notice that the Wuxi cocoon price, which roughly paralleled that of the Japanese cocoon price until the mid-1910s, began to dip consistently below the Japanese level thereafter.

The abrupt but sustained lowering of the level of cocoon prices after the mid-1910s reflected a systematic deterioration of cocoon quality in the Lower Yangzi as captured by the rising silk yield ratio—the amount of cocoons needed to produce a certain unit of raw silk. Shigema Uehara, the most authoritative specialist on Chinese silk industry at the time, presented data

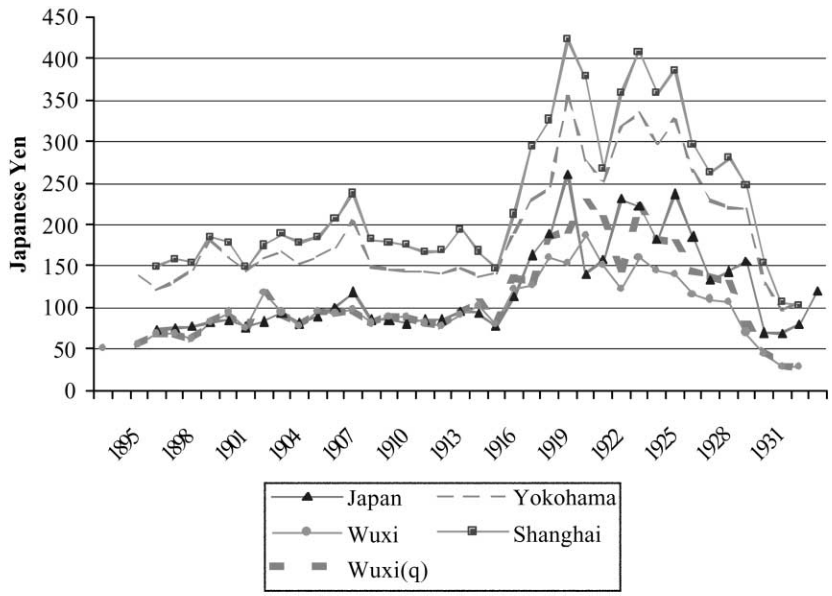

FIG. 1.—Cocoon and raw silk prices in Japan and the Lower Yangzi. The "Japan" and "Wuxi" series are for Japanese and the Lower Yangzi cocoon prices in 100 kilograms. *Wuxi(q)* stands for the quality adjusted price series. The "Yokohama" and "Shanghai" series are for raw silk export prices in 10 kilograms from Japan and the Lower Yangzi. Sources: For sources, see the data appendix. The Shanghai series for 1896–1917 is from Ziyu Chen, *Jindai Zhongguo de Zisi Saosi Gongye, 1860–1945* (The silk industry of modern China, 1860–1945) (Taipei: Institute of Modern History, Academia Sinica, 1989), p. 62; and that for 1917–32 is from Xin-wu Xu, ed., *Zhongguo Jindai Saosi Gongyeshi* (Modern history of Chinese silk-reeling industry) (Shanghai: People's Publishing House, 1990), pp. 692, 698. The Yokohama series is from Shozaburo Fujino, Shiro Fujino, and Akira Ono, *Estimates of Long-Term Economic Statistics of Japan since 1868* (Tokyo: Toyo Keizai Shinposha, 1979), 11:296–97. Exchange rates are from Liang-lin Hsiao, *China's Foreign Trade Statistics, 1864–1949* (Cambridge, Mass.: Harvard University Press, 1974), pp. 190–93.

showing that the amount of dried cocoon required for producing 100 kilograms of raw silk increased from 500 in 1915 to more than 600 kilograms in 1924—a decline of more than 20%.[8]

Adjusting the cocoon price by the quality change is essential for an accurate calculation of TFP changes for the Lower Yangzi. The quality-adjusted cocoon price in Wuxi (obtained by multiplying the cocoon price by the standardized silk-yield ratios) is displayed in figure 1 as Wuxi(q). The price dual TFP adjusted by cocoon quality (A_t^q) can be written as $A_t^q = \prod_{i=1}^{4} w_{it}^{\alpha_i} / S_t p_t$, with S_t and p_t denoting the standardized silk-yield and market cocoon price, respectively. For the Lower Yangzi, $S_t p_t$ is equivalent to Wuxi(q). The results for both regions are presented in table 1. Japanese TFP growth accelerated during these 3 decades. The Lower Yangzi showed very promising

TABLE 1

QUALITY-ADJUSTED TFP INDEX FOR JAPAN AND THE LOWER YANGZI

Japan		Lower Yangzi	
1903–9	105	1904–9	68
1910–19	119 (1.3%)	1910–19	86 (2.35%)
1920–28	157 (3.2%)	1920–28	79 (−.9%)
Average annual growth rate 1903–28	2.05%	Average annual growth rate 1904–28	.52%

SOURCES.—For sources of input and output prices and Chinese silk yield data, see the data appendix. Japanese silk yield data are from Shozaburo Fujino, Shiro Fujino, and Akira Ono, *Estimates of Long-Term Economic Statistics of Japan since 1868* (Tokyo: Toyo Keizai Shinposha, 1979), vol. 11, table 49, col. 4. The shares of labor, land, capital, and input (fertilizer being the major item) used for Japan are .5, .12, .2, .18, respectively, and .5, .17, .15, and .18 for the Lower Yangzi, respectively. The Japanese factor share information is from Central Committee of Japanese Sericultural Association, *Souen oyobi yousan keieihi no kenkyu* (Studies on the cost of mulberry cultivation and silkworm rearing), nos. 1, 2, 3 (1924 and 1925), report no. 1, p. 11; report no. 2, p. 19. For the Lower Yangzi, I have used information from Shigemi Uehara, *Shina Sanshigyo Taikan* (Overview of the Chinese silk sector) (Tokyo, 1929), pp. 83–84, 160; and also Ziyu Chen, *Jindai Zhongguo de Zisi Saosi Gongye, 1860–1945* (The silk industry of modern China, 1860–1945) (Taipei: Institute of Modern History, Academia Sinica, 1989), pp. 60–70.

NOTE.—Numbers in parentheses are growth rates compared with the earlier period. For the Lower Yangzi TFP, I used 1904 as the starting year because 1901–3 corresponded to an extraordinary period of cocoon market speculation in Wuxi due to a sudden surge of silk-reeling factories in Shanghai. This is explained in Sec. II*B* above. If I use 1901 or 1903 as the starting year, annual TFP growth rates in 1901–28 would be 1.5% and 1.1%, respectively. To test for the robustness of my TFP calculation, I have performed a sensitive test by applying alternative weights. Applying Chinese share weights on the Japanese data gives an average annual growth rate of 2.1% for Japan in 1903–28. Using Japanese share weights on Chinese data gives an annual TFP growth rate of 0.67% for the Lower Yangzi in 1904–28. Neither of these two rates was significantly different from those in this table.

TFP growth from about the 1900s to the 1910s, but this then turned negative in the 1920s as the silk yield decline took its toll. Overall, the Lower Yangzi TFP growth rate of 0.52% was only about a quarter of Japan's 2.05% in the first 3 decades of the twentieth century.[9]

II. Accounting for Growth: Technology and Commercialization

The leaders that came to power through the 1868 Meiji Restoration made no pretense of "restoring" Japan to its old days but, instead, proclaimed, in the new imperial "Charter Oath," that "knowledge shall be sought throughout the world" and subsequently embarked on a reform program to forge a modern nation-state modeled after the West.[10] Japan's decisiveness in turning outward in the face of the Western Imperialist challenge was matched by contemporaneous Qing's determination to reinstate an orthodox neo-Confucian ruling ideology to an empire that had been brought to the brink of collapse by the devastating 1860s Taiping rebellion.

The Qing bureaucrats did recognize the superiority of Western military technology and, under the so-called Self-Strengthening Movement (1860–94), attempted to modernize the Chinese military through a series of either government-financed or government-controlled Western style industrial enterprises. The attitude of the Self-Strengthening Movement toward private initiatives in the modern sector ranged from indifference to hostility and displayed little interest in supplying modern public goods; in most cases, this movement was even opposed to private efforts to build public infrastructure such as railroads and inland steam shipping.

In comparison, Meiji's sell-off of its limited number of government enterprises in the 1880s gave a powerful signal that the private sector was the mainstay of Japan's industrialization. The government concentrated on building crucial social and physical infrastructures such as a legal system, public education, research and technological diffusion, a modern monetary and banking system, modern transportation, and modern communication.

China's shocking naval military defeat by Japan in 1895 was soon to spell the end of the Self-Strengthening Movement and subsequently set off a process of intellectual awakening that questioned the fundamentals of the traditional system. The Qing constitutional reform in 1903–11, itself inspired and modeled after the Meiji reform, recognized the importance of the private sector and the government's role in public goods provision. But the imperial Qing collapsed in 1911, leaving an unfinished reform agenda to a China in disarray.[11]

The following three sections will show that these crucial changes in the late nineteenth and early twentieth centuries set the production and commercialization in Chinese and Japanese sericulture along increasingly divergent paths of technology and institutions despite similar starting points. This divergent path directly affected the productivities and competitiveness of the two sectors.

A. Technology

Japan was a latecomer in the global silk market. The rise of a domestic Japanese raw silk sector, originated in Tokugawa shoguns' 1685 restrictions against Chinese silk imports, was a case of import substitution based on the borrowing of the Chinese, particularly the Lower Yangzi sericulture technology. In the 1860s and 1870s, Japan became the most important supplier of quality silkworm eggs for Europe. Japan's comparative advantage in the export of silkworm eggs, a product lower in value added than raw silk, seems to corroborate other evidence that pointed to a level of late-Tokugawa Japanese technology, while possibly converging to or even overtaking that of the Lower Yangzi in the area of silkworm rearing, still lagging behind in mulberry cultivation and hand-reeling technique.[12]

Meiji reform opened Japanese sericulture to the world of European science and technology. The Iwakura mission that sent Meiji ministers on a 2-year study tour of Europe and America in 1871–73 enlightened Japanese sericulturalists as well. Following the official Iwakura mission to Italy was a group of Japanese sericultural experts headed by Nagaatsu Sasaki, who visited northern Italy in 1873.

At the time of Sasaki's visit, northern Italy represented the frontier of

Europe's sericultural technology, being transformed by the application of modern science, particularly the discovery and diffusion of Louis Pasteur's microscopic examination method of pebrine disease. The sericultural institute that Sasaki visited and studied for one full month in Gorizia (in northern Italy) was the first of its kind set up in 1869. Sasaki returned to Japan with the most up-to-date silkworm-rearing tools, such as microscopes and hygrometers, and actively advocated the establishment of modern sericultural research and education in Japan. The visit heralded the beginning of Japan's own national system of technological innovation, diffusion, and education. In the period between the 1890s and 1940s, Japanese sericultural specialists produced a steady stream of survey reports on foreign sericultural technology and commercial practices, with a total of about 40 volumes just on China.[13]

Such keen awareness of the ongoing technological revolution in European sericulture could not be found in the Lower Yangzi before the twentieth century.[14] Preparation for the grueling, pyramid-structured Civil Service Examination system based on the memorization of Confucian classics continued to engross the intellectual energies of the Chinese elites. Among the limited efforts by the Self-Strengthening bureaucrats to diffuse Western science and technology was the translation of a series of Western texts by the translating department of the Jiangnan Arsenal, a government industrial venture established to build Western-style military ships. One of these texts translated in 1899 is a classic Italian sericulture book, published originally in the late 1810s. The Chinese translation, itself possibly based on a late English translation, involved the work of three nonspecialists in sericulture—an Englishman by the name of John Fryer provided the oral interpretation of the text and two Chinese writers converted Fryer's verbal explanation into classical Chinese. This Chinese style of acquiring a classic but outdated Italian technology through a multiple of indirect media forms a direct contrast to the Japanese style of learning as displayed in Sasaki's 1873 study tour in Italy.[15]

By the turn of the century, Japanese surveys on Lower Yangzi sericulture had already shown important traces of technological divergence. These reports often criticized silkworm-rearing practices in the Lower Yangzi as backward, naïve, and superstitious, and most interestingly, "very much like our practices in the pre-Meiji era."[16] It confirms that Japanese sericultural technology began decisively to forge ahead of the Lower Yangzi only around the turn of the last century. The following comparative narrative illustrates two of Japan's most important technological breakthroughs in the early twentieth century that laid the foundation for its global dominance.[17]

Silkworm improvement: Developing the F_1 variety. Silkworm eggs are an essential input to cocoon production. While there were numerous technical innovations in the prevention of silkworm disease and improvement of silkworm varieties, the fundamental breakthrough came with the discovery of the so-called first filial (F_1) hybrid silkworm in the early 1910s. The performance of the F_1 variety surpassed the previous types in almost all technical indices.[18]

The concept of hybrid vigor behind the F_1 variety is ancient in East Asia.

However, previous studies and experiments with silkworm crossbreeding, including those done in the early Meiji era, were not supported by the theory of heterosis as expounded by Mendel's genetic principle. The key element of Mendel's discovery was that the superior traits of the two pure strain parent varieties were stable in their first generation of crossbreeds but not in the succeeding generations derived from this cross. This important theoretical recognition led to the rise of modern experimental labs that specialized in the selection and breeding of pure strain varieties and the mass production of the crossed F_1 variety silkworm eggs for cocoon production.

It is important to note that the success of the F_1 variety was founded on a series of cumulative research on embryology and cellular biology. Unlike other minor innovations, government-sponsored research labs and university departments were responsible for most of the basic scientific research and biological experiments at the core of the F_1 technology.[19]

Aided by a diffusion network of experimental stations, specialized silkworm-egg dealers, industrial silk reelers, and associations, the F_1 variety diffused rapidly among sericultural farmers. The diffusion started in the early 1910s, and by 1923, the F_1 variety's share in the spring crop reached 100%; by 1929, 100% of the summer and fall crop used the F_1 breed.[20]

The diffusion of the F_1 variety had a direct impact on both the productivity and quality of cocoons in Japan. The most commonly used indicator for the performance of silkworm varieties and rearing was the so-called cocoon-egg yield—the weight of cocoons obtained from a certain amount of hatched silkworm eggs. Table 2 shows clearly that the improvement of cocoon yield accelerated from 1900–1909 to 1910–19, which corresponded well with the timing and rate of diffusion of the F_1 variety. This also matched the acceleration of my TFP index for Japan. By the late 1920s, when the diffusion of the F_1 variety was complete, Japanese egg yields surpassed the level of Italy.

In contrast, silkworm eggs used in the Lower Yangzi before 1925 were almost entirely produced by traditional breeding methods, with little use of the microscopic method of disease prevention. Based on various Japanese survey reports, the final column of table 2 presents a direct comparison of the cocoon yield for these two regions. This contrast is compelling. Around 1900, the cocoon-egg ratios in Japan and the Lower Yangzi were roughly equal, but for the next 2 decades, the Japanese cocoon-egg ratio surged, as opposed to a largely immobile cocoon yield index in the Lower Yangzi.

Intensification: Rearing a second crop. The next major Japanese innovation was the rearing of a second crop of silkworms in the fall in addition to the main spring crop. Again, like so many other Japanese innovations, this one has its roots in East Asia.[21] However, instability in hatching and other technical problems constrained its growth. The great merit of the fall crop was that the timing of its rearing fell in the period when rice cultivation required the least labor, thus enabling cocoon growth without the sacrifice of cereal production.[22] In Japan, studies of artificial hatching started in the late 1880s, and Japanese farmers had also experimented with various crude meth-

TABLE 2

YIELD OF SILKWORM EGGS (Kilograms of Cocoons per Gram of Silkworm Eggs Hatched)

	Italy	France	Japan (All Crops)	The Lower Yangzi as a Percentage of the Japanese Level in That Year
1878–87	1.02	.94		
1888–1902	1.48	1.43	.86 (1899)	
1903–13	1.76	1.55	.80 (1900–1909)	100% (1900)
1910–19			1.06 (3.8%)	74% (1917)
1920–29	1.74		1.75 (5.2%)	50% (1927)

SOURCES.—Italian and French data are from Giovanni Federico, *An Economic History of the Silk Industry* (Cambridge: Cambridge University Press, 1997), appendix, table 15. I choose the *c* column for the Italian yield, which is the more consistent but also higher than the other estimate. Japanese data are from Shozaburo Fujino, Shiro Fujino, and Akira Ono, *Estimates of Long-Term Economic Statistics of Japan since 1868* (Tokyo: Toyo Keizai Shinposha, 1979), vol. 11, table 62. For Chinese data, the 1904 yield is from Kizo Minemura, *Shinkoku Sansigyou Sisatu Fukumeisho* (Survey report on the Chinese silk sector) (Tokyo: Ministry of Agriculture and Commerce, 1900), pp. 105–8. The yield for 1917 is for Zhejiang province given by Akaishi quoted in Katsuhiko Ikawa, *Kindai Nihon Seishigyo to Mayu Seisan* (Modern Japanese silk-reeling industry and cocoon production) (Tokyo: Tokyo Economic Information, 1998), p. 223. The 1927 data are from Shigemi Uehara, *Shina Sanshigyo Taikan* (Overview of the Chinese silk sector) (Tokyo, 1929), p. 30. Various estimates by Chinese scholars put the average cocoon yields in Jiangsu province of the late 1920s and early 1930s at roughly less than 1 kilogram per gram of eggs. See Su-Ping Yue, *Zhongguo Cansi* (Chinese silk) (Shanghai: World Press, 1935), p. 78; and Zhuang-Mu Wang, ed., *Minguo Sichou Shi* (History of silk in the Republic Era) (Beijing: China Textile Publishing House, 1995), p. 50.

ods of preserving and hatching the silkworm eggs in autumn. But it was not until Japanese scientists' discovery of hydrochloric acid processing in 1911–12 that the timing and outcome of artificial hatching stabilized.

Innovation in silkworm egg preservation and hatching was only half of the tale. The more binding constraint on the fall crop was the supply of mulberry leaves in the fall season when mulberry trees were no longer yielding fresh leaves. Technical innovation in this area had gone through several phases of search and experimentation and eventually converged to a set of three complementary technologies: the introduction and adaptation of a fertilizer-responsive tree variety, known as "Lu" from the Lower Yangzi; a new tree-pruning technique called "stem pruning"; and the adoption of new types of commercial fertilizer.

Japan had learned of the superior Lu mulberry trees through Chinese sericultural texts in the Tokugawa era but only started widespread introduction after Meiji through the advocacy of the energetic Sasaki. Stem pruning applied to the Lu types of trees reduced the tree trunks to bushes that matured faster, carried a higher yield, and could bloom multiple times within a year but that had a shorter life span.[23]

In China, the stem-pruning technique and bush type of mulberry trees (not the Lu type) were widespread in the subtropical Guangdong province.[24] Japan's success in transferring a subtropical technique to the temperate zone was complementary with the diffusion of new commercial fertilizers in 1900–1930. Among the types of commercial fertilizer used, soybean cake imported from Manchuria in northeast China was the most important.[25] The commercial adoption of the soybean cake from Northern China was a major historical achievement of Lower Yangzi agriculture in the eighteenth and nineteenth centuries. But by the twentieth century, Japan's colonial economic activities in Manchuria as well as significant improvements in internal distribution and transportation effectively diverted this trade flow toward Japan.[26]

This combination of technological innovation led to the rise of the ratio of the summer and fall crop to total output from just over 20% in the 1880–1900 period to 34% in 1900–1909, and, after 1920, the summer and fall crops consistently made up about half of the total output, rivaling the spring crop.[27]

By contrast, the early twentieth-century mulberry cultivation in the Lower Yangzi displayed an ecosystem formed since the late Ming (about the late sixteenth century). Mulberry trees, mostly of the Lu type, trunk-pruned, clustered along the banks of the canal system, fertilized by the canal sediments, with mulberry leaves transported to markets through the canal network.[28] Scattered estimates show that 1910–30 average Lower Yangzi mulberry yields per acre, while still higher than those for Gunma and Nagano prefectures for the period of 1880–90, the two most important sericultural regions in Japan, became only half of Japan's national average yield in 1927. Consequently, the share of summer and fall crops in the late 1920s Lower Yangzi remained at about the level of Japan before the 1880s.[29]

B. Commercialization

Japan: Breaking the resource constraint. In the 1880s the Suwa district of Nagano prefecture became the center of mechanized reeling factories. As Suwa was in the heart of the sericultural regions in eastern Japan, initially silk-reeling factories acquired cocoons directly from the rural households in neighboring areas. With the phenomenal growth of modern reeling factories over the next 2 decades however, silk reelers began to reach into other prefectures for additional supplies of cocoons at cheaper prices. Nationwide cocoon procurement by silk reelers induced the growth of cocoon collection and marketing centers in all of the major sericultural regions from the 1880s to the 1910s. These collection and marketing centers usually consisted of cocoon merchant houses as well as individual merchants, some equipped with cocoon drying and storage facilities.

The mountain-locked Suwa district was a harsh environment for commercialization. Therefore, the rapid extension of the radius of the cocoon supply region was a feat of man's triumph over geography. Nakabayashi has carefully documented how the adoption of modern insurance and transportation methods, the building of railroads, and the cooperation of silk reelers and railroad authorities had managed to break, one by one, the bottlenecks that would have otherwise constrained the enormous expansion of the cocoon supply. The building of railroads, starting in the early 1880s, instantly opened up new cocoon supply regions for the Suwa silk reelers, turning more and more traditionally integrated producers of silk-reeling and silkworm rearing into specialized cocoon farmers.

From the 1910s, the development of direct purchase arrangements between reelers and farmers expanded at the expense of intermediary markets or middlemen. After World War I, the direct exchange between reelers and farmers or farmers' cooperatives markedly increased. Statistics show that, by 1923, cocoons sold directly to the reelers were 46.6% of total sales, higher than the 23.9% and 29.5% sold through the cocoon market and merchants, respectively.[30] Out of the direct exchange system evolved another institutional innovation that brought reelers and rearers even closer, the so-called subcontractual direct purchase system. This system, which probably originated in 1905, entailed a long-term exchange contract between farmers and reelers. From 1926 to 1933, the share of cocoons sold through this system grew from 12.5% to 40.1% in Japan.[31]

The Lower Yangzi contrast: Growth and constraints. Compared with the almost linear progression of Japanese cocoon commercialization, the process for the Lower Yangzi was far more twisted. The period before the mid-1890s saw much activity but little real spread of modern silk-reeling factories. The exports of machine-reeled raw silk from Shanghai before 1894 were so insignificant that they were counted as hand-reeled raw silk in the customs statistics.

This is no surprise, as private modern industry, distinguished from those supported by the Self-Strengthening bureaucrats, had no legal status before the twentieth century. The few mechanized silk-reeling factories that did survive under the dubious extraterritorial protection in the treaty port of Shanghai were repeatedly harassed by the local officials representing the interests of the traditional silk weavers, who feared for their source of raw silk supply.[32] The issue was swept away by the treaty of Shimonoseki in 1895 signed after China's defeat by Japan granting legality to private enterprises in the treaty ports.

In Shanghai, the number of modern silk-reeling factories more than doubled between 1895 and 1896.[33] But the take-off of the Shanghai reeling industry, itself located about 200–300 kilometers from sericultural regions, soon ran into the constraint set by the nascent cocoon marketing and distribution infrastructure in rural Lower Yangzi, sending the cocoon price in Wuxi as presented in figure 1 to surge 70% between 1902 and 1903.

In the nineteenth century, the Lower Yangzi lowlands relied on its intricate waterways for cocoon transportation, thus barely surviving Qing's prohibition of railroads in China. Attempts by Shanghai silk reelers and merchants to introduce steamships into inner rivers were thwarted by local officials who were protecting the interests of traditional shippers. It was after 1896 with the signing of the Shimonoseki treaty that steamship and, later, regular steamer routes in the inner river and canal system began.[34] In 1908 and 1912, two railroads linking Shanghai to the sericultural heartlands of Jiangsu and Zhejiang provinces were also completed.

Lower Yangzi cocoon distribution was largely in the hands of the cocoon *hang*s. The *hang*s received fresh cocoons from farmers, dried them in their ovens, and then shipped them to Shanghai. Cocoon *hang*s belonged to the traditional Ya-hang system, in which the Ya-hang obtained local trading privileges by its purchase of government-issued licenses and payment of commercial taxes.[35]

The rising demand in the twentieth century induced a steady increase of cocoon *hang*s. In Wuxi, the number of cocoon *hang*s increased from fewer than 50 in 1895 to 140 in 1910. By 1917, Jiangsu and Zhejiang provinces had over 700 cocoon *hang*s scattered in major sericultural regions.[36] In 1902, Wuxi *hang* merchants, whose organizing activities to regulate market practices and coordinate collective action could be traced back to the 1880s, founded their official Cocoon Guild. This was absorbed in 1909 into a joint guild organization representing both the Lower Yangzi cocoon merchants and Shanghai silk reelers.[37]

Still, cocoon commercialization in twentieth-century Lower Yangzi was no smooth sailing. In the mid-1910s, at the peak of the Lower Yangzi cocoon commercialization, the traditional silk weavers' guild succeeded in pressuring the provincial governments to promulgate legislation to place a ceiling on the number of cocoon *hang*s allowed within a certain geographical area in the Lower Yangzi. Subsequently, the pace of growth of cocoon *hang*s and shipments to Shanghai noticeably slackened during the 1920s.[38]

Commercial organization in twentieth-century Republican China as characterized by guilds and *hang*s was a legacy of the traditional imperial system. In the Late Qing, strained by its deteriorating fiscal condition, the government increasingly resorted to commercial taxes in place of the rigid land tax. But the collection of commercial tax, particularly the infamous Lijing tax levied on goods in domestic transit, was in the hands of local governments whose revenue-extracting measures were often arbitrary and extortionary. It was the organized guilds, taking advantage of local governments' limited informational capacity on commercial activities, that acted as tax collection agents. Through the practice and spread of commercial tax farming, merchant guilds wielded additional leverage over rural cocoon distribution in the Lower Yangzi.[39]

Throughout this period, the Cocoon Guild, like the other guilds, resorted to all means to protect their trading privileges by shutting out independent cocoon intermediaries. Their efforts to collectively bargain down the purchase price for cocoons alienated cocoon farmers, who were constantly attempting to circumvent the *hang* system.[40]

A potential information problem emerged in the process of cocoon commercialization that created a division of labor between silkworm rearing and silk reeling. In scattered rural households where silkworms were reared, cocoon farmers had private information about their rearing process and the quality of their products. By the 1910s and 1920s, the fraudulent and dishonest practices of selling low-quality cocoons had turned the cocoon market into something like Akerlof's lemon market.[41]

Interestingly, Tokugawa Japan, especially in the eighteenth century, may have been no less guild-oriented than the Lower Yangzi. Official chartered merchant guilds paid license fees and contributed tax revenue to the Bakufu in exchange for trading privileges. It was Meiji reform that abolished the merchant guild system and upheld the legality of free commercial transactions.[42]

The absence of a government-sanctioned monopoly gave rise to the diversity of institutional arrangements of cocoon transactions in Japan and created possibilities for institutional innovation, as seen in the case of the "subcontractual direct purchase" system. Through the long-term direct purchase contract, industrial silk reelers, by providing scientifically bred silkworm eggs and detailed technical guidance, acquired a monitoring capacity of farmers' silkworm-rearing process. In Japan, large-scale, high-quality raw silk manufacturers such as Katakura and Gunze were the main users of this system.[43] The asymmetric information problem that had plagued the Lower Yangzi in the 1910s and 1920s, possibly causing the regions' silk yield decline, was eased by a system of semivertical integration in Japan.

C. A Summary Growth Accounting

The differential pace and sequence of cocoon commercialization in the two regions have productivity implications. Both visual observation and the standard statistical cointegration test on the price series in figure 1 reveal the much higher degree of market integration between Japanese cocoon markets and the Yokohama raw silk market than that between Wuxi and Shanghai in the first 2 decades of the twentieth century. Sericulture in the twentieth-century Lower Yangzi, possibly at a similar stage of commercialization as that in Japan in the latter half of the nineteenth century, might have realized significant productivity gains from new infrastructures and greater specialization. Such gains, however, may have been relatively insignificant for Japan in the twentieth century, as major infrastructures and a cocoon-marketing network were already well established. If we could assign the 0.52% annual Lower Yangzi TFP growth in 1904–28 in table 1 to possible efficiency gains from commercialization, we have to explain the 2.05% Japanese rate of TFP growth in 1903–28 in the context of the momentous technological and institutional innovations within its sericultural sector.[44]

Table 3 presents the growth accounting to calculate separately the contributions of input expansion (extensive growth) and TFP growth (intensive growth) to cocoon output growth for Japan. It shows that TFP growth (from table 1) made up 37% of the total growth in cocoon output, leaving the

TABLE 3

AVERAGE ANNUAL GROWTH RATES OF INPUT, OUTPUT, AND TFP IN 1903–27

	Japan	Lower Yangzi
Input expansion:		
Input (excluding summer and fall)	2 (42)	…
Intensification (summer and fall)	1.15 (21%)	0
Total factor productivity	2.05 (37%)	.52
Cocoon output	5.5	…
Raw silk exports	7.9	2.8

SOURCE.—For Japan, cocoon and raw silk data are from Shozaburo Fujino, Shiro Fujino, and Akira Ono, *Estimates of Long-Term Economic Statistics of Japan since 1868* (Tokyo: Toyo Keizai Shinposha, 1979), vol. 11, tables 57, 61, 63. For the Lower Yangzi, raw silk data are from Xin-wu Xu, ed., *Zhongguo Jindai Saosi Gongyeshi* (Modern history of Chinese silk-reeling industry) (Shanghai: People's Publishing House, 1990), pp. 690–92.

NOTE.—Numbers in parentheses indicate percentage contribution to growth rate of cocoon output. The 5.5% number is the Japanese cocoon growth rate adjusted by the silk yield. The growth rate without the quality adjustment is 5.2%.

remaining 63% to input expansion in 1903–28. Out of this 63% input expansion, I calculate the pure intensification effects from summer and fall crops using the following counterfactual calculation:

$$\text{Annual growth rate from intensification}$$
$$= \exp[\log(Q1927) - \log(Q_h 1927)]/24 - 1.$$

The expression $Q1927$ = total spring, summer, and fall cocoon output in 1927; Q_h1927 = 1927 spring cocoon output + ($Q1927 \times$ 1903 summer and fall ratio).

This calculation, as presented in table 3, shows that intensification through the summer and fall crop (as a part of the input expansion) was equivalent to an annual 1.15% input growth (about 21% of the total growth in cocoon output). Altogether, TFP growth and intensification accounted for 58% of the annual growth in Japanese cocoon output, leaving the remaining 42% to pure expansion in land and labor.

I showed earlier that the TFP growth was directly related to the discovery and diffusion of the F_1 variety, while intensification was achieved through the application of artificial hatching in combination with the set of complementary technologies in mulberry cultivation. These constituted the core of the induced innovation in Japanese sericulture. Had such innovation not occurred, that is if we remove the 58% contribution of the induced innovation from the 5.5% annual cocoon growth rate in 1903–27, Japanese growth would have been only 2.3%. This is roughly equivalent to the 2.8% growth rate of the raw silk exports in the Lower Yangzi in the same period. Clearly, what ultimately made the difference between these regions is the race-seed-fertilizer transformation.[45]

III. An Epilogue: The Lower Yangzi Catch-up in the 1930s

The lackluster sericultural performance in twentieth-century Lower Yangzi has to be placed in the larger context of China's political disintegration and social and economic dislocation that occurred after the Qing collapse in 1911. Under a series of weak governments or sometimes no government in the Republican period, real reforms made little headway. Yet the legacy of reform and the fundamental ideological switch proved to be far more enduring.

In 1897, a local magistrate founded China's first modern sericultural institute in Hanzhou, Zhejiang province. Sericultural manuals with titles using the newly introduced term "experiment" appeared after 1900. The Late Qing reform, which abolished the Civil Service Examination, paved the way for a modern educational system with a new curriculum. Slowly but steadily, experimental stations, research institutes, schools of various levels, departments in universities, and a scientific community grew, actively promoting sericultural reform, popularizing scientific principles, and diffusing new technology.[46]

The first 2 decades of the century also heralded the so-called golden age of Chinese capitalism in the treaty port of Shanghai. Rapid industrial and financial growth in Shanghai was spilling over to the Lower Yangzi, especially along the recently completed Shanghai-Nanjing railroad on which Wuxi was located. By the mid-1920s, Wuxi, with its cheap labor and proximity to raw materials, had emerged as a second center of modern silk-reeling production in the Lower Yangzi.

The scattered mosaics of economic growth seemed to really come together with the founding of the new Nationalist government in Nanjing, Jiangsu province, in 1927. The restoration of general peace and stability was an invaluable public good that a government could offer. By 1933, for the first time the number of modern silk-reeling machines in Wuxi exceeded those in Shanghai.[47] Most notable was the rise of a giant silk-reeling conglomerate, the Yongtai Company, which moved from Shanghai in 1926. It soon emerged as the industry leader in pushing for sericultural improvement and technological diffusion in the 1930s.

In 1928, the Nationalist government abolished the trading privileges of the Cocoon Merchant Guild, lifted the restrictions on the opening of cocoon *hang*s, and started reforms in commercial taxation and tax farming. Between 1928 and 1929, the number of cocoon *hang*s in Wuxi county jumped by about 30%.[48] The government encouraged the establishment of silkworm-rearing cooperatives to sell cocoons directly to reeling factories. In 1932, the Yongtai Reeling Company began to set up long-term exclusive contracts with farmers or cooperatives in the Lower Yangzi, a system very similar to the subcontractual direct purchase system pioneered by the large silk reelers in Japan.[49]

Starting in 1932, the provincial governments of both Jiangsu and Zhejiang began to take a direct role in promoting sericultural improvement and tech-

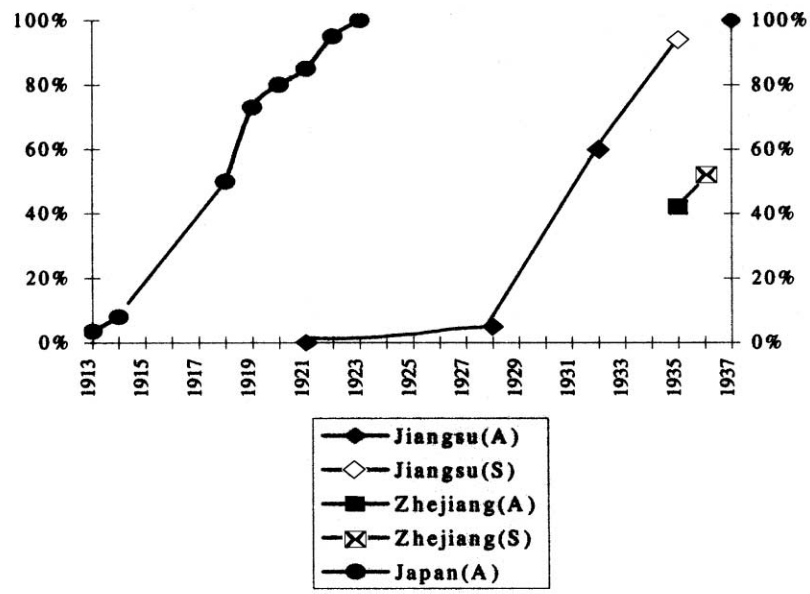

FIG. 2.—Diffusion of scientifically produced silkworm varieties in Japan and the Lower Yangzi. Sources: Diffusion figures for Japan were adapted from Yukihiko Kiyokawa, "The Diffusion of New Technologies in the Japanese Sericulture Industry: The Case of the Hybrid Silkworm," *Hitotsubashi Journal of Economics* 25 (1984): 31–59, esp. p. 41, fig. 1. *A* includes all crops, while *S* includes only spring crops. For China, see Saiichi Benno, "Chugoku No Nogyo Kindaika Ni Taisuru Teiko" (Resistence toward Chinese agricultural modernization), *Shakai Keizai Shigaku* 59, no. 2 (1993): 30–59, esp. p. 43; Zhuang-Mu Wang, ed., *Minguo Sichou Shi* (History of silk in the Republic Era) (Beijing: China Textile Publishing House, 1995), pp. 10, 49; and Y. Robert Eng, *Economic Imperialism in China: Silk Production and Exports, 1861–1932* (Berkeley: University of California Press, 1986), p. 136.

nological diffusion by designating model districts across the region. In 1934, the government founded a national level sericultural research and improvement organization.[50]

The outcome was a 1930s Lower Yangzi catch-up with Japan that was nothing short of remarkable. Figure 2 plots the Lower Yangzi diffusion curve for the scientifically improved variety, mostly of the F_1 types. For Jiangsu province, the percentage of scientifically produced silkworm eggs increased from 5% to almost 100% within only 5–7 years. Diffusion lagged somewhat in Zhejiang, but the overall rate of diffusion in the Lower Yangzi in the 1930s was comparable to the Japanese diffusion of the F_1 hybrids in the 1910s and 1920s.

Following the Japanese method of artificial hatching, Jiangsu province took the leadership in rearing fall silkworms. In 1935, the ratio of fall crops to total crops was 42% for Jiangsu and 18% for Zhejiang province.[51]

The distinctive imprint of Japanese technology and institutions on the

Lower Yangzi path of catch-up was unmistakable. This came about by no accident but was the outcome of 2 decades of conscious Japanese learning on the part of Chinese sericulturalists and later the Wuxi entrepreneurs. Lower Yangzi's success in a near full-scale transplantation of the Japanese sericultural model attests to the binding power of comparable conditions of factor endowments and a common cultural and technological heritage between the two regions. It also bears witness to the early twentieth-century momentous reversal of the historical direction of knowledge transfer between these regions from the premodern era.[52]

Cocoon output and raw silk exports from the Lower Yangzi increased in 1935 and 1936. Equipped with the newly imported Japanese reeling technology, raw silk by Yongtai conglomerate cut into the U.S. silk stockings market, formerly the exclusive territory of the giant Japanese high-quality raw silk producers such as Katakura and Gunze.

The positive developments centered around Wuxi sent alarms to the Japanese competitors. Despite its global dominance in the 1930s, Japanese competitiveness in this labor-intensive product was rapidly eroding due to rising labor costs brought about by decades of economic growth. The massive outflow of Japanese technology was only chipping away at its last line of defense.[53] Therefore, the 1930s Lower Yangzi catch-up was riding the historical shifting tides of dynamic comparative advantage, only to be abruptly brought to a halt by Japan's full-scale invasion of China in 1937.

IV. Conclusion

Around the middle of the nineteenth century when Western imperialism opened up East Asia, China, by all measures of comparative advantage, seemed set on a course of regaining its historical supremacy in the global silk market. Instead, the 6 decades to follow were to witness the rise of Japan against all odds.

This article demonstrates that induced technological and institutional innovation brought Japanese sericulture decisive productivity advantages over that of the Lower Yangzi, the key to its dominance in the twentieth-century global raw silk market. It further argues that the rise of induced innovation in Japan and its absence in the Lower Yangzi during this period has to be analyzed in the context of the two countries' contrasting ideological and political responses to the mid-nineteenth-century Western imperialist challenge, leading to economic policies drastically different in the provisioning of public goods, the structuring of economic incentives, and the alignment of interest groups. Therefore, the case of the Lower Yangzi's remarkable convergence to Japan in the 1930s was as much in the areas of technology and commercialization as in ideology.

This, however, begs the larger question: why, when confronted with the same Western challenge, had Japan's ideological or cognitive switch been earlier and more decisive? This is a question of enormous import to our understanding of economic development that would call upon a much more comprehensive and multidisciplinary approach than the scope of this article allows.

This comparative analysis contributes both a historical and an East Asian perspective to the theory of induced innovation. In Japan and the Lower Yangzi, the development of technology biased toward using labor and saving capital and land as a response to the rising labor-land ratio had been a long-standing tradition traceable to Tokugawa Japan and Southern Song China (1127–1279).[54] Even in the twentieth century, the two Japanese epochal technical innovations in crossbreeding and summer and fall crops were ancient in origin but achieved fundamental breakthroughs with the infusion of modern science, the establishment of a national diffusion network, the build-up of modern physical and social infrastructure, and the rise of new systems of production and distribution.

Clearly, what set the Japanese induced innovation in the modern era apart from that of the premodern is not its direction of technical bias but, rather, its sharply accelerated pace of technical progress due to the availability of the newly supplied public or social capital to create economy-wide externalities. While some of these externalities, as shown by the Japanese experience, can be partially internalized by the large and integrated reeling firms that acted as powerful agents of change, such a possibility was stymied in the Lower Yangzi—the growth of its mechanized reeling industry was both belated and geographically removed from the rural sector as a consequence of China's fragile legal environment for the private sector.

Judged in this light, the late nineteenth-century and early twentieth-century growth record of the Lower Yangzi sericulture was quite impressive and historically unprecedented if measured by the standards of the sixteenth and seventeenth centuries, when Chinese raw silk still reigned supreme globally. It pales in comparison to Japan only in its fast track of modern economic growth.

Finally, this article also sheds light on the ongoing historical debate on China related to the so-called Needham puzzle—why China, with its significant scientific achievements and relatively flexible economic institutions, failed to become the first country to industrialize. The related grand hypotheses ranging from "high level equilibrium trap" to "involution" and to the recent California school's resource constraint argument, all grounded in some form of resource and factor endowment explanation seem to have neglected the important lesson from Japan's rapid industrialization in the twentieth century in the face of overpopulation, labor abundance, and resource scarcity.[55] Openness, by which I mean not only opening the country to trade, but also opening the minds of its populace, clearly matters.

Data Appendix

I. Averages of Nominal Input and Cocoon Price Indices for Japan and the Lower Yangzi

	The Lower Yangzi					Japan				
	Labor	Land	Capital (Draft Animal)	Input (Bean Cake)	Cocoon	Labor	Land	Capital	Input (Fertilizer)	Cocoon
1901–9	100	100	100 (1906)	100	100	100	100 (1903)	100	100	100
1910–19	169	152	149	109	98	173	200	140	127	118
1920–28	220	197	202	130	119	369	369	261	173	215

Sources.—For the Lower Yangzi, the cocoon price in Wuxi: for 1901–20 it is from Katsuhiko Ikawa, *Kindai Nihon Seishigyo to Mayu Seisan* (Modern Japanese silk-reeling industry and cocoon production) (Tokyo: Tokyo Economic Information, 1998), table 2, pp. 304–5; for 1920–24, it is converted from Shigemi Uehara, *Shina Sanshigyo Taikan* (Overview of the Chinese silk sector) (Tokyo, 1929), p. 225. Data for 1925–27 are unavailable; I projected them from the 1924 cocoon price level using the 1925–27 market price of raw silk. The 1927–29 cocoon price is from Jing-Yu Gao and Xue-xi Yan, *Jindai Wuxi Cansi Ye Ziliao Xuanji* (Selected materials on the modern silk industry and sericulture) (Jiangsu People's Press and Jiangsu Classics Press, 1987), pp. 88–89. The market price of raw silk in Shanghai is from D. K. Lieu, *The Silk Industry of China* (Shanghai, Hongkong, and Singapore: Kelly & Walsh), appendix, table 4. The original 1912 price for fresh cocoons in Ikawa is 24, which seems implausibly low. I adjusted it to 28.5 using the cocoon price in Ziyu Chen, *Jindai Zhongguo de Zisi Saosi Gongye, 1860–1945* (The silk industry of modern China, 1860–1945) (Taipei: Institute of Modern History, Academia Sinica, 1989), p. 62. The farm wage index, land price index, and farm animal price index in the Lower Yangzi are from John Buck, *Land Utilization in China* (Nanjing: University of Nanking, 1937), vol. 3, table 5, pp. 151–52, table 10–1, p. 168, and table 6, p. 153. The soybean cake price is from Liang-lin Hsiao, *China's Foreign Trade Statistics, 1864–1949* (Cambridge, Mass.: Harvard University Press, 1974), pp. 80–81. There were no consistent long-term price series data for fertilizer and capital stock in the Lower Yangzi; I used the prices of bean cake and draft animals as proxy prices. None of these two inputs were used on a large scale in the Lower Yangzi, and their inclusion could lead to possible biases in TFP. Considering that their share is relatively small (12% and 18%), the biases may not be so serious and could potentially offset each other. Japanese cocoon price, land price, current input, and capital prices are from M. Umemura, S. Yamada, Y. Hayami, N. Takamatsu, and M. Kumazaki, *Agriculture and Forestry*, vol. 9, *Estimates of Long-Term Economic Statistics of Japan since 1868* (Tokyo: Toyo Keizai Shinposha, 1966), col. 11 of table 7, cols. 3 and 13 of table 34, and col. 6 of table 31.

Note.—Numbers in parentheses indicate the earliest available data.

II. Lower Yangzi Silk Yield Data

The following table from Shigemi Uehara, *Shina Sanshigyo Taikan* (Overview of the Chinese silk sector) (Tokyo, 1929), p. 225, is the Wuxi silk yield data in kilograms of dried cocoons required to produce 100 kilograms of raw silk.

Year	Before 1916	1916	1917	1918	1919	1920	1921	1922	1923	1924
Wuxi	520	550	510	560	620	600	670	590	680	620

Uehara also listed silk yields of three other sericultural districts in the Lower Yangzi. They all showed a declining trend similar to that in Wuxi.

Silk yield in the 1900s and the early 1910s was around 500. For 1903, see Kizo Minemura, *Shinkoku Sansigyou Sisatu Fukumeisho* (Survey report on the Chinese silk sector) (Tokyo: Ministry of Agriculture and Commerce, 1900), p. 148; and for 1910, see Kouhisa Ootori, *Shina Seijyou no Kenkyuu* (Tokyo: Houbunsha, 1919), pp. 177–78. Various reports confirm that by the late 1920s and early 1930s, it had become a standard practice in the Lower Yangzi to use 620–50 for cocoon silk conversion; Jing-Yu Gao and Xue-xi Yan, *Jindai Wuxi Cansi Ye Ziliao Xuanji* (Selected materials on the modern silk industry and sericulture) (Jiangsu People's Press and Jiangsu Classics Press, 1987), p. 75; Saiichi Benno, "Chugoku No Nogyo Kindaika Ni Taisuru Teiko" (Resistence toward Chinese agricultural modernization), *Shakai Keizai Shigaku* 59, no. 2 (1993): 30–59, esp. pp. 32, 43.

For computing the TFP, I used the Wuxi silk yield. For 1903 and 1910, I used the silk yield of 500. Linear interpolation is applied for the interval years between 1903 and 1916. For silk yields after 1924, the averages of 1920 through 1924 are used.

Notes

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1. Lillian Li, *China's Silk Trade: Traditional Industry in the Modern World, 1842–1937* (Cambridge, Mass.: Harvard University, Council on East Asian Studies, 1981), p. 77; Ippei Yamazawa and Yuzo Yamamoto, *Estimates of Long-Term Economic Statistics of Japan since 1868* (Tokyo: Toyo Kiezai Shinposha, 1979), 14:5. Globally, the combined exports of China, Japan, and Italy consistently accounted for more than three-fourths of world raw silk trade.

2. See Giovanni Federico, *An Economic History of the Silk Industry* (Cambridge: Cambridge University Press, 1997), chap. 3, p. 36, table 3.4; p. 200, table AIII.

3. Except for Lillian Li's "Silks by Sea, Trade, Technology and Enterprise in China and Japan," *Business History Review* 56 (1982): 192–217, and Yukihiko Kiyokawa's "Senzen Chugoku No Sanshi-gyo Ni Kansuru Jyakkan No Kousatsu" (A few observations on the prewar Chinese silk sector), *Keizai Kenkyu* 26, no. 3 (July 1975): 240–55, most studies as seen in the references usually focus either on China or Japan. Federico's work covers the global raw silk industries.

4. The Lower Yangzi region, located in the central eastern part of China, consists of the provinces of Jiangsu, Zhejiang, and Anhui. The average size of a sericultural farm in Japan was about 0.5 acre in the 1900s and 0.7 acre in the 1920s. For the Lower Yangzi, the average size was a little less than 0.5 acre in the early 1930s. For Japan, see Shozaburo Fujino, Shiro Fujino, and Akira Ono, *Estimates of Long-Term Economic Statistics of Japan since 1868* (Tokyo: Toyo Keizai Shinposha, 1979), 11: 151. For the Lower Yangzi, see Toua Kenkyujyo, *Keizai ni Kansuru Shina Kanko*

Chosa Houkokusho (Investigative report on Chinese customs related to economic activity) (Tokyo: Toa Kenkyuu Jyo, 1944), pp. 26–28. In this study, I did not specifically include another major export-oriented silk-producing region, the Guangdong province in southern China. The subtropical Guangdong reared the multivoltine type of silkworms that could hatch and spin cocoons five or six times a year. The quality of Guangdong raw silk was inferior, and possibilities for technological transferability from the temperate zones were also more limited.

5. Yujiro Hayami and Vernon Ruttan, *Agricultural Development: An International Perspective* (Baltimore: Johns Hopkins University Press, 1985).

6. For Japanese cocoon output data, see Fujino, Fujino, and Ono, table 57, col. 5. For the Lower Yangzi, see Y. Robert Eng, *Economic Imperialism in China: Silk Production and Exports, 1861–1932* (Berkeley: University of California Press, 1986), table 2.7, p. 35.

7. The Japanese data are from Fujino, Fujino, and Ono, pp. 306–7. Data for the Lower Yangzi delta in the late 1920s were based on the following sources: Toua Kenkyujyo, pp. 27–28; Shigemi Uehara, *Shina Sanshigyo Taikan* (Overview of the Chinese silk sector) (Tokyo: Ogada Nichieido, 1929), pp. 132–33; Su-Ping Yue, *Zhongguo Cansi* (Chinese silk) (Shanghai: World Press, 1935), pp. 169–70; and Ziyu Chen, *Jindai Zhongguo de Zisi Saosi Gongye, 1860–1945* (The silk industry of modern China, 1860–1945) (Taipei: Institute of Modern History, Academia Sinica, 1989), pp. 68–69.

8. Uehara's book, totaling over 1,000 pages, was an encyclopedic coverage of the Chinese silk sector, based on 5 years of travel through 18 provinces. For details on silk yield data by Uehara, see the data appendix.

9. Federico did a primal input-output-based TFP calculation for Japanese sericulture from about 1890 to 1929 using only land and labor as inputs. His estimate of annual TFP growth of 2.6% (for the spring crop only), ignoring other inputs such as fertilizer and equipment that grew much faster than land and labor, represents an overestimate (Federico, p. 85). This lends further support to my 2.05% price dual TFP estimate based on a more complete coverage of inputs.

10. See Marius B. Jansen, *The Making of Modern Japan* (Cambridge, Mass.: Harvard University Press, 2000), p. 355.

11. For the Tongji Restoration, see Mary Wright, *The Last Stand of Chinese Conservatism: The T'ung-Chih Restoration, 1862–1887* (Stanford, Calif.: Stanford University Press, 1962). For the Self-Strengthening Movement, see chaps. 9 and 10 in John K. Fairbank, ed., *The Cambridge History of China*, vol. 10, *Late Ch'ing, 1800–1911*, pt. 1 (Cambridge: Cambridge University Press, 1978). For the Late Qing reform, see chaps. 5 and 7 in John K. Fairbank and Kwang-ching Liu, *The Cambridge History of China*, vol. 11, *Late Ch'ing, 1800–1911*, pt. 2 (Cambridge: Cambridge University Press, 1980). Tomoo Suzuki, *Yo Mu Undou No Kenkyu* (A study of the westernization movement in China) (Tokyo: Kyuko Shoin, 1992). For Japan, see Thomas Smith, *Political Changes and Industrial Development in Japan: Government Enterprise, 1868–1880* (Stanford, Calif.: Stanford University Press, 1955.

12. For Chinese influence on Japanese sericultural technology, see Tosio Furushima, *Furushima Tosio Cyosakusyu* (Collected works of Tosio Furushima) (Tokyo: University of Tokyo Press, 1975), 5:384; 6:630. Zenjirou Inoue, "Yousan Gijutus no Tenkai to Sansho" (Sericultural technique and manuals), in *Nihon Nousho Zenshuu*, ed. Nousan Gyouson Bunka Kyoukai (Tokyo: Nousan Gyosan Bunkka Kyoka, 1976), 35:465–70. For pre-Meiji Japan's relative position in sericultural technology, see L. Li (n. 3 above); and Kanji Ishii, *Nihon SanshiGyo Shi BunSeki* (Analysis of Japanese silk industry) (Tokyo: Toyo Keizai Shinpousha, 1972), p. 374.

13. Editorial Committee of Japanese Silk History, *Nihon Sanshigyousi* (History of Japanese sericulture and reeling) (Tokyo: Japanese Sericulture and Silk Association, 1935), 4:282; 3:503, and 3:219. For Sasaki's visit, see Istituto Bacologico Sperimentale

di Gorizia, *Annuario dell' Istituto Bacologico Sperimentale di Gorizia, Seitz* (Gorizia, 1874), p. vi.

14. In the 1880s, Paul Brunat, the French silk-reeling expert and entrepreneur who had helped found Japan's large-scale government-run Tomioka Silk Reeling plant in the 1870s, was the manager of an American-funded silk-reeling plant in Shanghai. In 1886, when Li Hongzhang, the leader of the Self-Strengthening Movement, visited his factory, Brunat made a direct appeal for the need of introducing microscopic examination in China. Brunat's appeal, reported in the Shanghai newspapers but clearly ignored by Li and others, caught the attention of Japanese bureaucrats at the Ministry of Agriculture and Commerce, who translated this news piece into Japanese. Alarmed by the potential possibility of silkworm disease in Japan, technicians at the ministry conducted microscopic examinations on silkworm eggs in Japan, only to be shocked by the prevalence of disease already in Japan. This finding, according to these bureaucrats, was one important reason behind the promulgation of the Silkworm Disease Prevention Law in Japan in that year. See *Dai Nippon Sanshi Kaihou* (Report of the Sericultural Association of Japan), no. 178, March 20, 1907, p. 39. Also see Kazuko Furuta, "Kindai Seishigyou No Douryu to Kounan Shakai no Taiou" (The introduction of modern sericulture and the response of Jiangnan society), in *Kindai Nihon to Ajia* (Modern Japan and Asia), ed. Hirano Keniichirou (Tokyo: University of Tokyo Press, 2000), p. 96.

15. This Chinese translation of this Italian sericulture book by Vincenzo Dandolo can be found at the East Asia Library of the Hoover Institute at Stanford University. I thank Claudio Zanier for the information on Dandolo. For John Fryer, see Fairbank (n. 11 above), 10, pt. 1: 536. For the tradition of Japanese directly translating Chinese and Western works (especially in the Dutch Studies period in Tokugawa) and the contrasting tradition of Chinese intellectuals dependent on Western scholars' oral interpretation of Western works in Ming and Qing, see chap. 8 of Tingjiu Li and Atsushi Yoshida, *Zhongre Wenhua Jaoliu Shi Dashi: Keji Juan* (History of Sino-Japan cultural exchange: Science) (Hangzhou: Zhejiang People's Publishing, 1996).

16. See Nakajiro Takatsu, *Shinkoku Sanshigyo Shisatsu Houkokushou* (Reports on China's sericultural sector) (Tokyo: Ministry of Agriculture and Commerce, 1898), p. 16; Zenshino Oishi, *Shinkoku Kouso Sekko Ryoushou Sanseishi Chousahoukokusho* (Survey reports on the silk sectors of Jiangsu and Zhejiang provinces) (Tokyo: Tokyo High School of Commerce, 1908), p. 8. Hitosi Matunaga, *Shinkoku SanGyo Sisatsu Fukumeisho* (Survey report on Chinese sericulture) (Tokyo: Ministry of Agriculture and Commerce, 1898), pp. 3–5.

17. It is worthwhile to note that Europe had for long sought East Asian sericultural technology, whose global leadership may have been maintained as late as the eighteenth century. This European quest culminated in the publication of two translated works of Chinese and Japanese sericultural texts in 1837 and 1848. See Claudio Zanier, *Where the Roads Met: East and West in the Silk Production Processes (17th–19th Century)* (Kyoto: Italian School of East Asian Studies, 1994), pp. 71–94.

18. Lab tests confirmed that the F_1 variety shortened the rearing period, produced longer fibers, yielded fewer defective cocoons, and was better suited to the demands of machine reeling. See Yukihiko Kiyokawa, *Nihon No Keizai Hatten To Gijutsu Fukyu* (Japanese economic development and technological diffusion) (Tokyo: Toyo Keizai Shinpousha, 1995), pp. 91–92.

19. Yukihiko Kiyokawa, "The Diffusion of New Technologies in the Japanese Sericulture Industry: The Case of the Hybrid Silkworm," *Hitotsubashi Journal of Economics* 25 (1984): 31–59, pp. 37–38.

20. For a diffusion curve, see Kiyokawa, "The Diffusion of New Technologies in the Japanese Sericulture Industry." The diffusion of the F_1 variety led to the standardization of silkworm egg varieties used nationally and thus to more uniform types of raw silk, a feature highly favored by the increasingly mechanized U.S. market. For

the growing importance and eventual dominance of the U.S. market for raw silk in the twentieth century, see Debin Ma, "The Modern Silk Road: The Global Raw-Silk Market, 1850–1930," *Journal of Economic History* 56, no. 2 (1996): 330–55.

21. Zhu Xin-yu pointed out a method of artificially prolonging the silkworm egg hibernation period in low temperature recorded in a Chinese sericultural manual dated 1273 A.D.; see Xin-yu Zhu, *Zhong Guo Si Chou Shi* (History of Chinese silk) (Beijing: Textile Publishing, 1992).

22. For a linear-programming-based study analyzing the gains of allocative efficiency from summer and fall crops, see the work by Le Thanh Nghiep and Yujiro Hayami included as chap. 6, "The Tradeoff between Food and Industrial Crops: Summer-Fall Rearing of Cocoons," in *The Agricultural Development in Modern Japan: A Century's Perspective*, ed. Yujiro Hayami and Saburo Yamada (Tokyo: University of Tokyo Press, 1991), pp. 175–98.

23. For the cumulative improvements of the Lu mulberry trees in the Lower Yangzi over almost a millennium, see chap. 4 of Fagen Ji, ed., *Shichou zi Fu Huzhou yu Sichou Wenhua* (Silk city Huzhou and silk culture) (Beijing: China International Broadcasting Publishing House, 1994). As European sericulturalists had long learned about and experimented with the Lu variety in Europe (which they named the "Philippine variety"); see Zanier, p. 74. Sasaki himself recalled that he owed his knowledge of the Lu tree to the works of Kaibara Ekiken (1630–1714), Tokugawa Japan's foremost scholar on the philosophy of Confucius and on Chinese botany. See *Dai Nippon Sanshi Kaihou* (Reports of the Sericultural Association of Japan), no. 176 (1907), pp. 24–26; Editorial Committee (n. 13 above), 4:80; and Zanier, p. 74. For the advantages of the stem-pruning technique, see Katsuhiko Ikawa, *Kindai Nihon Seishigyo to Mayu Seisan* (Modern Japanese silk-reeling industry and cocoon production) (Tokyo: Tokyo Economic Information, 1998), chap. 3.

24. For the stem-pruning method in China, see Jiamian Liang, ed., *Zhongguo Nonye Kexue Jishu Sigao* (History of Chinese agricultural science and technology) (Beijing: Agricultural Publishing, 1989), pp. 219–20. For the bush type of mulberry trees in Guangdong province, see C. P. Howard and K. P. Buswell, *A Survey of the Silk Industry of South China* (Canton, 1925), chap. 3.

25. Other commercial fertilizers used were fish cakes and, later, modern chemical fertilizer; see Ikawa, chap. 8; and Hayami and Yamada, eds., chap. 4.

26. For soybean in the Lower Yangzi, see Keiji Adachi, "Daizukasu Ryutsuu to Shindai no Shougyouteki Nougyo" (Distribution of soybean cake and the commercialization of Qing agriculture), *Touyoushi Kenkyu* 37, no. 3 (1978): 35–63. For Japan's internal transportation and distribution improvements and the activities of large Japanese shipping companies and trading houses, such as Mitsui and Mitsubishi in Manchuria, see Ikawa, chap. 8.

27. Data on the ratio of the summer and fall crops in 1880–89 are from Kiyokawa, *Nihon No Keizai Hatten To Gijutsu Fukyu* (Japanese economic development and technological diffusion), pp. 60–62. The rest is from Fujino, Fujino, and Ono (n. 4 above), vol. 11, table 57, cols. 6, 7. The Lu type and its close relatives represented the single most important variety, accounting for one-fifth of mulberry acreage in Japan by 1920. Lu trees also crossed with other varieties and could use different names. Besides Lu, Meiji Japan introduced other varieties of mulberry from other sericultural regions in China as well as other parts of the world, including Italy, India, and South America. By the 1910s and 1920s, the stem-pruned type of mulberry tree formed about 60% of all mulberry trees in Japan. By the 1920s, almost 70% of the mulberry fields in Japan could supply leaves for both the spring and fall crops in a year. See Editorial Committee, 4:14, and 4:105–13; Ikawa, chap. 3; and Fujino, Fujino, and Ono, 11:155.

28. Ikawa, pp. 227–31.

29. For Chinese mulberry yield, see ibid., p. 231; Yue (n. 7 above), pp. 19, 71;

Jing-Yu Gao and Xue-xi Yan, *Jindai Wuxi Cansi Ye Ziliao Xuanji* (Selected materials on the modern silk industry and sericulture) (Jiangsu People's Press and Jiangsu Classics Press, 1987), pp. 10–11; Shanghai International Testing House, *A Survey of the Silk Industry of Central China* (Shanghai, 1925), pp. 88, 92. The Gunma and Nagano yield are from Ikawa, pp. 230–31. Japanese national average yield in the 1920s is from Editorial Committee (n. 13 above), 4:319–20. For the Lower Yangzi share of summer and fall crops in the 1910s and 1920s, see Ikawa, p. 225; and Toua Dobun Kai, *Shina Nen Kan* (China annals) (Tokyo: Toua Dobun Kai, 1917 and 1919).

30. The narrative so far is based on Ishii (n. 12 above), pp. 397–405; and Masaki Nakabayashi, "Seishi Gyo no Hattatsu to Kansen Tetsudo" (Development of silk reeling and main rail lines), in *Meiji no Sangyo Hatten to Shakai Shihon*, ed. Naosuke Takamura, Meiji Industrial Development and Social Capital (Tokyo: Minerva, 1997).

31. Ishii (n. 12 above), pp. 423–29.

32. For the troubles of modern silk-reeling factories in Shanghai, see Suzuki (n. 11 above), pp. 325–33. The fragility of private enterprise in nineteenth-century China can best be illustrated by the fate of an indigeneous modern private silk-reeling industry in rural Guangdong. The mechanized silk-reeling factories, set up by an overseas Chinese merchant in 1872, grew rapidly within a few years but were faced with riots from traditional silk weavers and subsequently ordered to close by the local magistrate. See Debin Ma, "Europe, China and Japan: Transfer of Silk Reeling Technology in 1860–95," in *Asia Pacific Dynamism, 1550–2000*, ed. A. J. H. Latham and Heita Kawakatsu (London: Routledge, 1998).

33. Xin-wu Xu, ed., *Zhongguo Jindai Saosi Gongyeshi* (Modern history of Chinese silk-reeling industry) (Shanghai: People's Publishing House, 1990), p. 615.

34. Under the treaty system, steamship companies were allowed to ply the Yangzi river and the coast but not the inner rivers or canals. The government did compromise in 1889 to grant the use of steamers in towing traditional boats in 1889; Suzuki (n. 11 above), p. 347.

35. For commercial organization in Qing China, see Susan Mann, *Local Merchants and the Chinese Bureaucracy, 1750–1950*, (Stanford, Calif.: Stanford University Press, 1987); for cocoon hangs, see L. Li (n. 1 above), pp. 176–85; Saburo Soda, *Chugoku Kindai Seishi Gyo Shi No Kenkyu* (Study on the modern Chinese silk industry) (Tokyo: Kyuko Shoin, 1994), pp. 389–404; Gao and Yan, pp. 18–19.

36. Soda, p. 417.

37. See chap. 4 of Lynda Bell's *One Industry, Two Chinas: Silk Filatures and Peasant-Family Production in Wuxi County, 1865–1937* (Stanford, Calif.: Stanford University Press, 1999); Suzuki, p. 406; Soda, pp. 416–22.

38. Soda, pp. 423–44; and Bell, pp. 79–80. The average metric tons of annual cocoons shipped from the sericultural regions in the Lower Yangzi to Shanghai in the period of 1900–1909 were 9,767. This number increased to 21,303 tons for 1910–19 but only to 27,152 tons for 1920–28. See Uehara (n. 7 above), pp. 227–28 for 1913–28; and Akira Sitou, *Shinkoku Sansigyou Ippan* (An examination of the Chinese silk sector) (Tokyo: Raw Silk Inspection Bureau of Ministry of Agriculture and Commerce, 1911), pp. 120–22 for 1898–1911.

39. For Qing's fiscal system, see Yeh-chien Wang, *Land Tax in Imperial China, 1750–1911* (Cambridge, Mass.: Harvard University Press, 1993); Bell, pp. 83–87; Mann.

40. Bell, p. 82; and Soda, p. 427. The cocoon hang system had a control of about 40%–60% of all total cocoons sold in the Lower Yangtze. Federico (n. 2 above), pp. 148–49.

41. There were systematic efforts by the farmers to mix inferior quality cocoons with better quality cocoons; see L. Li (n. 1 above), p. 185; and Soda, pp. 433–44.

42. For an English-language account of the rise, fall, and revival of the merchant guild system (Kabu Nakama) in the Tokugawa period, see Charles Sheldon, *The Rise*

of the Merchant Class in Japan, 1600–1868 (New York: Augustin, 1958). For the Meiji abolishment of guilds, see Ryousuke Ishii, *Houseishi* (Legal history) (Tokyo: Yamagawa Publishing, 1965), p. 261.

43. Ishii (n. 12 above), pp. 57–83, 429. Among the eight variables used in Kiyokawa's probit regression, the subcontractual direct purchase system was the leading variable in explaining the rapid diffusion of the F_1 variety (Kiyokawa, "The Diffusion of New Technologies in the Japanese Sericulture Industry" [n. 19 above], p. 47).

44. For efficiency gains from commercialization in twentieth-century China, see Earnest Liang, "Market Accessibility and Agricultural Development in Prewar China," *Economic Development and Cultural Change* 30, no. 1 (October 1981): 77–105; and Loren Brandt, *Commercialization and Agricultural Development: Central and Eastern China 1870–1937* (Cambridge: Cambridge University Press, 1989).

45. Hayami and Yamada ([n. 22 above], chaps. 5 and 6) conducted counterfactual statistical analysis on what the performance of Japanese agriculture would have been like had developments in commercial fertilizer and summer and fall crop not occurred. Had Hayami conducted a comparative study of China and Japan, he would have felt less need for his counterfactual exercise. The Lower Yangzi sericulture unfortunately supplied exactly the factual side of Hayami's counterfactual of Japanese agriculture in the early twentieth century.

46. Zhuang-Mu Wang, ed., *Minguo Sichou Shi* (History of silk in the Republic Era) (Beijing: China Textile Publishing House, 1995), pp. 45–46, 87. For a list of sericultural texts, see Zhu (n. 21 above), app. 1. For the growth of modern academic communities and institutions after the twentieth century, see chap. 8 of John Fairbank and Albert Feuerwerker, *The Cambridge History of China,* vol. 13, *Republican China, 1912–1942*, pt. 2 (Cambridge: Cambridge University Press, 1986).

47. It is important to note that the emergence of the Suwa district as Japan's premium silk-reeling production center was the spread of modern banking and other service facilities throughout Japan in the nineteenth century. See Ishii (n. 12 above), chap. 2. For banking and service developments in Wuxi, see Chen (n. 7 above), chap. 2; and Gao and Yan (n. 29 above).

48. Mann argued that tax-farming practices did not disappear but were taken over by specialized tax-farming agents (Mann, n. 35 above), chap. 9.

49. See Toua Kenkyujyo (n. 4 above), pp. 63–69; Gao and Yan, pp. 305–8.

50. Tetsu Okumura, "Kyoko Ka Kosetsu Sanshigyo no Saihen" (Restructuring of the Jiangsu and Zhejiang silk industry under the Great Depression), *Toyoshi Kenkyu* 37, no. 2 (1979): 80–116; Saiichi Benno, "Chugoku No Nogyo Kindaika Ni Taisuru Teiko" (Resistence toward Chinese agricultural modernization), *Shakai Keizai Shigaku* 59, no. 2 (1993): 30–59; Zhuang-Mu Wang (n. 46 above), pp. 64–86.

51. For a penetrating analysis of factors accounting for the lag in diffusion of the improved variety in Zhejiang, see Benno. The ratio of fall crops is calculated from Toua Kenkyujyo (n. 4 above), p. 298.

52. Although European and American individuals and organizations also made positive contributions to sericultural improvements, the Japanese model eventually took dominance in the Lower Yangzi, as confirmed by the large number of sericultural reformers holding Japanese degrees, direct participation of Japanese specialists in Lower Yangzi sericultural schools, and extensive introductions of Japanese sericultural technology in journals and books in the 1920s and 1930s. See Kazuko Furuta, "Technology Transfer and Local Adaptation: The Case of Silk-Reeling in Modern East Asia" (Ph.D. diss., Princeton University, 1988), pp. 117–82; and Zhuang-Mu Wang (n. 46 above). For a description of Chinese copying the Japanese model of reform, see Douglas Reynolds, *China, 1898–1912: The Xinzheng Revolution and Japan* (Cambridge, Mass.: Harvard University Press, 1993).

53. For cocoon output and raw silk exports, see Chen, p. 109; and Okumura.

For imports of Japanese silk-reeling technology in Wuxi and Yongtai's marketing activities in the United States, see Gao and Yan, pp. 325–29, 362–64. For Japanese investigators' warnings of the Lower Yangzi competition in the 1930s, see Benno, pp. 32, 39.

54. Francesca Bray, *Science and Civilisation in China*, vol. 6, *Biology and Biological Technology, Part II: Agriculture* (Cambridge: Cambridge University Press, 1984), pp. 609–10.

55. For a recent debate on this issue, see the articles that appeared in *Journal of Asian Studies* 61, no. 2 (May 2002): 501–663.

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