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Working Paper

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Working Paper, No. 176

Provided in Cooperation with:
George J. Stigler Center for the Study of the Economy and the State, The University of Chicago Booth School of Business

Suggested Citation: Braguinsky, Serguey; Ohyama, Atsushi; Rose, David (2002) : Cooperative Technology Adoption Under Global Competition: The Case of Japanese Cotton Spinning Industry, Working Paper, No. 176, The University of Chicago, George J. Stigler Center for the Study of the Economy and the State, Chicago, IL

This Version is available at:
https://hdl.handle.net/10419/262578

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Cooperative Technology Adoption Under Global Competition: The Case of the Japanese Cotton Spinning Industry

by

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Abstract

This paper presents a model of technological cooperation between firms in infant industries that was inspired by the spectacular growth of the Japanese cotton spinning industry beginning in the 1880s. Information sharing accelerates diffusion of new technologies developed by more advanced countries and results from what we call the neighboring farmer effect – the willingness to help competitors when output price is fixed. Technologies that produce industry-wide benefits are crucial for industry development but are subject to sub-optimal provision because of free-riding. To mitigate this problem, Japanese firms devised a sophisticated institutional arrangement to increase the private returns to innovation.

[JEL classification numbers: L20, O31]

7 July 2002

*Braguinsky received financial support from the J.M. Olin Program in Law and Economics at the University of Chicago Law School and the George Stigler Center for the Study of the Economy and the State. We thank Gary Becker, Dennis Carlton, Salavat Gabdrakhmanov, Boyan Jovanovic, Josh Lerner, Steven Levitt, Sam Peltzman and participants in the University of Chicago Economics and Legal Organization workshop for helpful comments. All remaining errors are ours.

Competition is essential to the innovation process and to capitalist economic development more generally. But so is cooperation. The challenge ... is to find the right balance of competition and cooperation, and the appropriate institutional structures within which competition and cooperation ought to take place. [David Teece, 1992, p. 1]

I. Introduction

How can less developed countries foster development of their infant industries? The rapid growth of the Japanese cotton spinning industry beginning in the 1880s provides a textbook case for exploring this question. Japan was the first East Asian country to industrialize on its own and cotton spinning was Japan's first major success in industrialization (Saxonhouse, 1974). Industry growth was phenomenal, with total output of cotton yarns rising more than 20 fold from 1888 to 1900. This phenomenal growth occurred in the absence of a large domestic market for cotton yarns or contemporaneous growth in other industrial sectors, so it was clearly not the result of "Big Push Industrialization" (Murphy, Shleifer and Vishny, 1989), yet it nevertheless did appear to spur subsequent industrialization in Japan.

The historical record shows that Japanese cotton spinning industry growth was driven by rapid innovation; from innovation came lower production costs and from lower production costs came expanded firm and industry output. These innovations were largely local adaptations of new technologies developed by more advanced countries, most notably England. Modern cotton spinning firms, in particular the Osaka Spinning Company, then invaded the traditional cotton fabrics industry and completely transformed it in the first two decades of the 20th century. The development of the cotton textile industry in Japan was therefore consistent with the development process envisioned by Parente and Prescott (1994, 1999), who view growth as depending critically on the "technology adoption decision."

Although the market for cotton yarns was highly competitive and Japanese cotton spinning firms enjoyed no infant industry protection from their government, firms cooperated extensively with one another to introduce innovations that dramatically improved the global competitiveness of the industry as a whole. Contrary to the implications of any existing model that we know of, cooperation emerged in the total absence of any form of monopoly power. Under highly competitive market conditions Japanese firms even devised sophisticated

institutional mechanisms to solve a crucial free-rider problem associated with innovations that produce industry-wide benefits. In this paper we investigate the role that cooperation between competing firms may play in accelerating the rate of adoption of new technologies by examining the development of the Japanese cotton spinning industry. In doing so, we hope to shed light on the general process of innovation-led industrial development in the kind of infant industries commonly found in less developed countries.

Was cooperation among Japanese cotton spinning firms simply a case of Japanese exceptionalism? We do not believe so. Instead, we conclude from the Japanese experience that under global competition, an infant industry environment naturally provides incentives for cooperative efforts to increase the pace of technological adoption. To exemplify the fundamental economic forces at work we propose a simple model of technological cooperation in an infant industry environment. In the model we show that it is privately optimal for firms to share information about how to use new technologies under local conditions. Such sharing drives technological diffusion time to zero, so it also increases the average rate of innovation and, hence, the rate of industrial development. We call this the neighboring farmer effect. We show that the more closely an industry fits the description of an infant industry, the stronger this effect tends to be. The model also predicts that as an industry matures eventually both the neighboring farmer effect and the cooperative behavior it supports will disappear.

The kind of technological innovation we consider here is one that lowers production costs for any firm in the infant industry that adopts the innovation. We assume that the cost reduction experienced by firms in the infant industry is lower than the cost reduction that would be experienced by firms outside of the industry because firms in the infant industry possesses a comparative advantage in the use of the innovation. This assumption is consistent with recent work by Keller (2002), who has shown that technological spillovers tend to be local and not global in scale. This assumption is also particularly relevant to the analysis of less developed countries because a common feature of such countries is low skilled, low cost labor. Countries that invent new technologies typically enjoy high skilled but high cost labor. It follows, then, that new technologies that happen to work well with low skilled labor may confer a comparative advantage to infant industries in less developed countries. Since a comparative advantage can confer a cost advantage to firms in the infant industry that will not be dissipated by price

competition as long as the infant industry remains small relative to the world market, such innovations are crucial for infant industries to expand market share.

Our model is related to the literature on endogenous growth in that we assume that the process of technological innovation is costly (Aghion and Howitt, 1992; Grossman and Helpman, 1994). The innovations we consider result from the adoption of technology developed in more advanced countries, not the research and development of new scientific ideas. In many such cases a new technology is adopted simply through the purchase of new capital so it is natural to view technological adoption as a firm-specific investment (Parente, 2000). But while the use of new capital may be firm-specific and therefore private incentives may lead to a socially efficient outcome, information about the use of new capital is very likely to be nonfirm-specific.

Such information can be extremely valuable. Before any firm in an emerging industry can adopt a new technology by purchases new capital it must first learn of such opportunities, determine whether the new capital can be profitably deployed under local conditions, and learn how to use it as well as train its workers. Even new techniques that can be learned "off the shelf" from the production floors of firms in more advanced countries must be discovered and then adapted to local conditions and this process is costly (Pack and Westphal, 1986; Grossman and Helpman, 1994). Resources expended to gather such information typically constitute a nonfirm-specific investment because what any firm learns about using a new technology under local conditions is of use to other firms in the infant industry which share the same local conditions.

In the model we develop in this paper we find that if an infant industry is small relative to the global market (hardly an unusual case) then even in the absence of patent protection or monopoly power conferred by market structure it is still privately profitable for firms to invest in gathering such information. This is so because as long as output price does not fall in response to technological innovations that lower production costs, firms can retain rents from a successful innovation even if spillovers cannot be controlled or payments cannot be extracted from other firms in the industry that may benefit from the innovation. Moreover, we show that even if such information can be easily concealed it will be privately optimal for firms to share it so the rate of spillover will be endogenously set equal to 1. All firms in the infant industry can earn rents as long as such a situation persists, so in such cases an industry should expand over time both through the growth in the sizes of existing firms and through new entry. This is exactly what

happened in Japanese cotton spinning. Eventually, however, the industry will reach a size at which the general equilibrium effects of its growth can no longer be ignored – price taking and the neighboring farmer effect resulting therefrom disappear and, with it, cooperative information sharing. We deal with this case in the extension of the basic model in Section VI.

Although we show that the infant industry market structure naturally provides incentives for information sharing, we also show that the level of total industry investment in information gathering and adaptation of new technologies to local conditions will tend to be sub-optimal. This creates an incentive for the industry to effect greater inter-firm cooperation through institutional arrangements aimed at bringing the rate of innovative activity closer to its efficient level. The need for such cooperation arises from "follower" firms free-riding off the information gathered and developed by "leader" firms that are so large that investment in such activities is privately optimal for them. Inasmuch as sharing information may result in attempts by some firms to free-ride off of the costly innovative effort of others, firms can be expected to devise mechanisms to mitigate the adverse effects of such behavior. This part of our paper is related to the observations made by Rosenberg (1963) in the context of the machine tool industry (see also Mowery and Rosenberg, 1989) and to a more recent paper by Lerner and Tirole (2000) who discuss this issue in the context of open source software development. An important private incentive scheme that Japanese firms used to address the free-rider problem was the awarding of specific prizes to innovating firms. Close-knit relations among firms facilitated credible *ex ante* commitments to make *ex post* payments to a successful innovator who had invested in an innovation from which the industry as a whole profited. A firm's reputation as a successful innovator was also important for its long-term success in many other respects, not the least of which was enhanced ability to obtain capital funding in the environment where capital markets were very poorly developed.

Japanese firms also resolved the free-rider problem through a consciously designed institutional arrangement in the form of an industrial association. This association provides an example of the kind of cooperative R&D cartel extensively studied in the literature in the past two decades (see, for example, Katz, 1986; D'Aspermont and Jacquemin, 1988; Kamien, Muller and Zang, 1992; Suzumura, 1992). One of the most important findings of this literature is that with sufficiently large spillovers, there are strong incentives for firms to cooperatively conduct R&D even though they might compete in the output market and that such cooperation improves

welfare (D'Aspermont and Jacquemin, 1988, pp. 1134-35; Suzumura, 1992, Theorem 2; Kamien et al., 1992, Proposition 1). In our model, the highest possible spillover rate arises endogenously because all firms belong to a small, globally open industry which puts them in a market structure in which competing firms in the industry are not rivals and thus lose nothing by sharing information with each other. We can then use the conclusions from the above mentioned literature to argue that inasmuch as the resulting cooperative generation of new knowledge accelerates technological adoption for the industry as a whole, it confers an advantage over other (less globally oriented) infant industries that produce the same good.

In the next section we discuss the neighboring farmer effect in more detail. In Section III we review the history of the development of the Japanese cotton spinning industry. In Section IV we present a model of technological adoption for firms in an infant industry environment that reveals the potential for technological cooperation in a globally competitive environment and also reveals the problem of sub-optimal investment of resources to search for and learn to use new technologies developed by firms in more advanced countries. In Section V we discuss the ways in which this problem can be resolved through a system of using innovation prizes to align private incentives and through institutional arrangements devised for that purpose. In Section VI we analyze the dissipation of the neighboring farmer effect as the industry matures. We conclude the paper in Section VII by discussing the implications it has for fostering industrial development in less developed countries today as well as point toward more general implications of our analysis.

II. The Neighboring Farmer Effect and Incentives to Innovate and Share

If a corn farmer discovers that a new type of plow works exceptionally well with his type of soil, he can either share or conceal such information. We suspect that most farmers do not conceal such information and that many are even eager to share it. We believe such neighborly behavior results from the fact that corn farmers are price takers in the corn market. The argument is simple. If there were only two farmers in the corn market then Bertrand price competition would result in all profits being dissipated if the information is shared, so it is not shared.[1] But if there are so many farmers that all take price as given and only the first farmer and his neighbor

[1] Cournot competition results in a reduction in profit that becomes greater the greater is the number of firms.

experience the cost reduction, then their costs fall but the price does not, so the first farmer can share such information without fear that his own profit will fall.

Now suppose that there are several farmers in the area with this unique kind of soil and that the new type of plow only significantly improves productivity when used on this kind of soil. In this case there is a comparative advantage conferred to farmers in this area in the use of this type of plow. If the set of all farmers in the area is sufficiently small relative to the entire market for corn, then they are collectively price takers and therefore the farmer that first discovered the advantage of using the new type of plow can share this information with all of the other farmers in the area without fear that his own profits will fall because copying the innovation outside the area does not produce as significant an increase in productivity.

One could argue that there is still a cost associated with sharing information – the opportunity cost of not extracting some kind of payment for it.[2] But in many cases the value of information cannot be ascertained by a potential buyer without revealing the information itself (see, e.g., Katz, 1986). Especially if the basic underlying innovation is patented by a firm in an advanced nation, the first firm in the infant industry to learn of its potential use probably has no standing to license or patent this knowledge. By concealing its information it can at most force other local firms to duplicate its research and to incur the same costs it has incurred, so that absent output market rivalry such behavior does not serve any useful purpose and it is at least weakly dominated.

In short, if local conditions confer a comparative advantage in the use of a given technology to a particular infant industry, then more often than otherwise there is no cost associated with sharing information about that technology with other firms in the infant industry.[3] As a result, any benefit from sharing such information (or any kind of cost associated with concealing) is sufficient to make sharing a strictly dominant strategy. Two such benefits are immediately obvious. First, there are potential benefits from reciprocity. Second, even if an *ex ante* licensing scheme is unfeasible (because of the aforementioned verification problem or

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[2] We thank Henry Manne for pointing this out.

[3] If a comparative advantage is not conferred by local conditions, one could argue that a firm in the infant industry might conceal an innovation if diffusion from the set of firms in the infant industry to the rest of the world is rapid and there is no first-mover advantage. Recent empirical work by Keller (2002) strongly suggests, however, that technology diffusion tends to be very local, which is consistent with the argument that the comparative advantage of employing a particular technology differs across locations.

because of imperfect credit markets), a credible commitment to an *ex post* transfer payment can be extracted in the context where the same firms repeatedly interact with each other.

What if small firms exploit the fact that it may be optimal for a single, large firm to invest in innovation regardless of what other firms do?[4] This is a case in which reciprocity provides no benefit for the innovating firm, and an *ex-post* transfer mechanism may also be ineffective. However, there may still be significant costs associated with not sharing. For example, if the innovating firm conceals what it learns about new technologies, other firms will have an incentive to raid workers to learn of such innovations as soon as possible. Although what is sought by raiding firms is nonfirm-specific knowledge, the raided firm will nonetheless lose its share of the value of raided workers' firm-specific human capital. So even in this extreme case it is in the best interest of innovating firms to share what they learn right away (we will see that the desire to avoid such raiding of workers was indeed a strong motivation for leading firms in the Japanese cotton spinning industry).

Since firms will tend to share innovations, the benefits of any nonfirm-specific innovation will spill over immediately to all firms in the infant industry. As a result, any firm can free ride off the innovative efforts of other firms. Therefore an important problem for industrial development in Japan was (and continues to be elsewhere) that of driving-up the total level of industry investment in innovations that generate industry-wide benefits.[5] Firms in infant industries therefore have an incentive to engage in another form of cooperation, that of devising incentive schemes to alleviate the free-riding problem associated with innovations that produce industry-wide (nonfirm-specific) increases in productivity. But regardless of how successful an infant industry is in addressing this problem, sharing information about innovations increases the rate of industrial development because new ideas are employed by all firms immediately instead of spreading at the natural rate of diffusion.

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[4] We will show in Section IV that under very general assumptions the largest firm will nearly always find it optimal to innovate even if all other firms are expected to free-ride off of its efforts.

[5] Note that while sharing is the dominant strategy, sharing is not the cause of sub-optimal investment. If an innovation is of benefit to all firms in the infant industry, it makes no difference whether the innovation is conceable and, if conceable, it makes no difference whether the innovating firm shares information. In all cases the industry-wide (social) demand for such innovations will exceed the demand of the innovating firm.

III. The Emergence of the Japanese Cotton Spinning Industry

The traditional cotton spinning industry was all but wiped out after Japan opened up to foreign trade in the late 1850s. Initially, the government tried to assist the set-up of a modern industry by establishing government-owned and government-operated spinning mills. These mills were entrusted with the task of adapting and spreading modern Western (mainly English) technology in Japan. By any measure all of those ventures failed (see Ohyama, Braguinsky, Murphy, 2001 for a recent account). Most notably, they failed to develop a single important managerial or technological innovation over the whole period of their existence. By the early 1880s the modern cotton spinning industry was still virtually nonexistent with 95% or more of Japanese consumption of cotton yarns coming from imports (mainly from England and India).

The first genuinely private modern enterprise, the Osaka Spinning Company (OSAKA), started operating in 1883. In 1886 the government, prompted by a budget crisis, abandoned its subsidies to cotton spinning firms and adopted a laissez-faire policy toward the industry.[6] Paradoxically, this was followed almost immediately by rapid industry growth, with output rising by more than 20 times from 1888 to 1900, and 2.8 times more from 1900 to 1914. Industry-wide labor and capital productivity each more than doubled between 1890 and 1916. The value of exports exceeded that of imports in 1897 and by 1900 Japan was already exporting more than half of its domestic output of cotton yarns. Overall, according to an authoritative study by Saxonhouse, "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).

Historical records leave little doubt that it was the leading role of OSAKA that jump-started this spectacular development. Being the only modern firm in the industry, OSAKA assumed the role of the industry leader and invested heavily in searching for and learning how to use new technologies developed by more advanced countries, particularly England.

Employing approximately 10,500 spindles, in contrast to 2,000 spindles which was the standard technological choice in Japan at the time, OSAKA's sheer initial size constituted a major innovation. Because almost all existing mills in Japan before OSAKA had employed water power they had to be located by rivers in the mountainous areas. The steam engine technology

[6] We should perhaps also mention here that there was basically no tariff protection in place at that time since Japan was still confined to a 5% ceiling on import tariffs imposed by international treaties it signed back in 1866.

adopted by OSAKA enabled it to locate the factory at the heart of the prospering commercial city of Osaka (which gave its name to the firm), providing easy access to markets. OSAKA introduced the double shift system which helped raise its return on capital. To reduce the risk of using kerosene lamps during the night shift, it was also the first Japanese spinning mill to use electricity. Although these innovations were not original, they were not costless. The choice of steam power was made after more than a year of conducting feasibility studies. Letters written by Eichi Shibusawa, the company founder, reveal how costly in terms of time and effort it was to raise the capital needed to finance the initial scale of a mill that was 5 times larger than what was considered standard by Japanese investors at the time. Having been a successful banker and merchant, the risk to his professional reputation was also substantial.

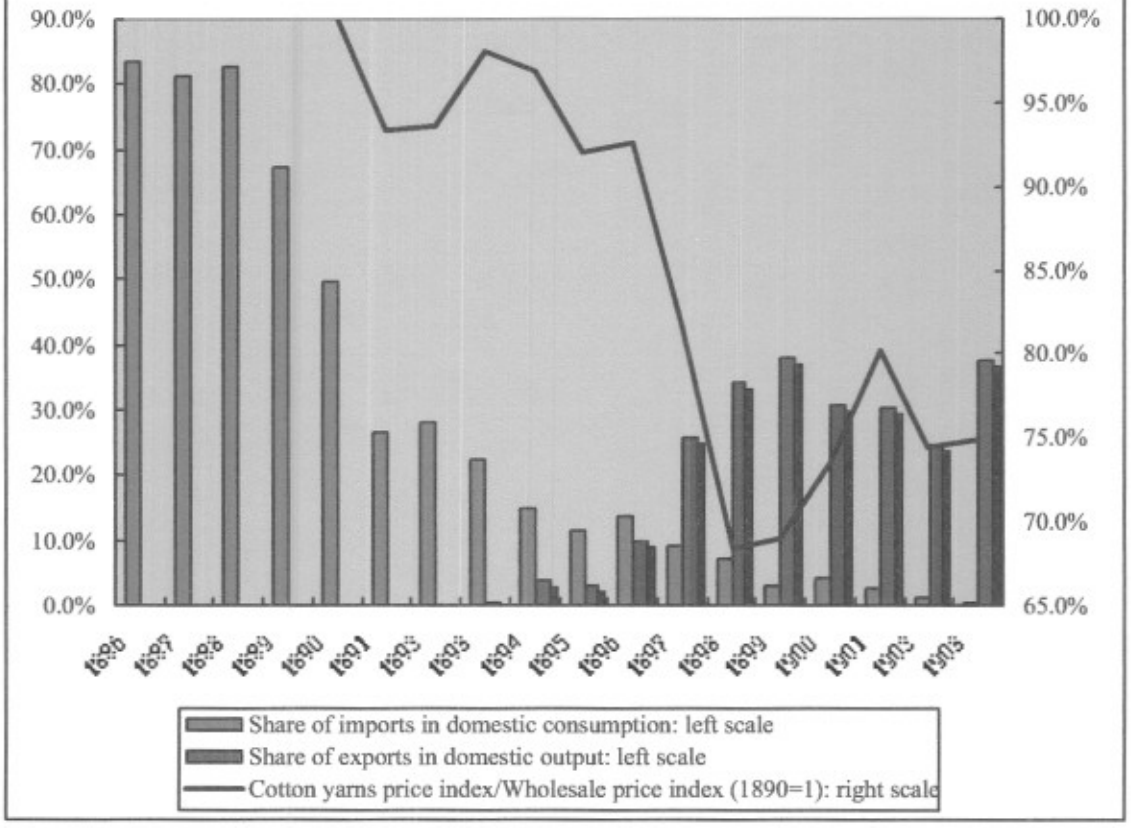
Perhaps the most costly (and important) innovation of all was the investment that Shibusawa made in training Takeo Yamanobe. Yamanobe was hired to become OSAKA's chief engineer and was trained for three years in England prior to starting operation. As a result, OSAKA became the first Japanese spinning mill to employ a native chief engineer. In contrast, all previously established, government-sponsored firms employed British chief engineers who had trouble adjusting their knowledge to the Japanese environment and communicating it to native workers.

Although it was OSAKA that invested in the human capital of Takeo Yamanobe, the innovations that resulted from this investment were readily shared with all of the formerly government-sponsored firms and new entrants. This is particularly noteworthy since in the early stage of industrial development there was little reason for OSAKA to expect lessor firms to reciprocate in kind. OSAKA's decision to invest in its ability to adapt new technologies from countries like England was clearly vindicated by the fact that Yamanobe became the greatest authority for the industry as a whole for years to come.

At the time, domestic output still comprised a small share of cotton yarns consumption even in the domestic market in Japan (Figure 1), and sharing did not have any adverse effects on OSAKA's profits (see Table 1). The effect that such sharing had on other firms in the industry can be clearly seen by comparing Tables 2 and 3. By the middle of 1889, 10 out of 18 of the previously existing firms, following OSAKA's example, had increased their sizes. Many of those firms had also copied OSAKA's other innovations (more so in introducing the double shift, less so in switching to steam power) and those that did grew more than those that did not. Following

OSAKA's lead clearly helped those firms attain the goal of profitability, although on average the profits of older firms were still half that of OSAKA's profits.

Figure 1. Share of imports in domestic consumption, share of exports in domestic output and the relative price of cotton yarns (1886-1903)



Source: Calculated from the data in Takamura, 1971, Vol. 1, p. 183, Vol. 2, p. 82; Ohkawa et al., 1967; Tokeihyo for various years.

Much more important than its effect on existing firms was the effect of OSAKA's success on the entry of new firms from the late 1880s to the early 1890s. Almost all new entrants (there were 10 of those in 1886-1889) employed the technological choices of OSAKA from the very start of their operations and they were also able to achieve positive profits from the very beginning (Table 3).

As can be seen from Table 3, in 1889 there were 28 firms operating in the cotton spinning industry in Japan. This number continued to grow for another 10 years. As the number of firms benefiting from costly innovations undertaken by OSAKA (and then also other firms) continued

to rise, some compensation mechanisms started to emerge that gave innovators extra incentives to invest in innovations having industry-wide benefits. An early example was one of the most important breakthroughs in the Japanese cotton spinning industry – the development of a new supply of raw cotton in the same year of 1889.

Table 1. The Performance of Osaka Spinning Company, 1883-1889

Semi-annual reporting periods	Profits/Sales ratio	Annualized return on capital employed	Annualized return on shareholders' capital	Annualized dividends on shareholders' capital
1883.II	30.8%	5.7%	8.4%	6%
1884.I	42.6%	19.2%	30.8%	18%
1884.II	26.6%	15.7%	25.9%	18%
1885.I	14.5%	5.3%	6.6%	10%
1885.II	12.9%	6.6%	8.7%	12%
1886.I	19.5%	9.3%	11.1%	9%
1886.II	27.3%	21.4%	28.9%	16%
1887.I	33.1%	33.4%	47.8%	26%
1887.II	34.1%	36.5%	60.8%	34%
1888.I	35.0%	35.6%	56.1%	36%
1888.II	25.1%	21.7%	31.7%	30%
1889.I	20.0%	16.6%	24.9%	27%
1889.II	24.6%	16.4%	29.3%	20%

Source: Toyo Boseki, 1986, Vol. 1, p. 52.

All firms that had entered the market before OSAKA used domestically grown cotton which was of very poor quality and for which supplies were too limited to cope with large scale industry demand. In 1884-85 the demand from the Osaka Spinning Company alone accounted for more than 10% of the whole raw cotton available in the Osaka area market (Toyo Boseki, 1986, Vol. 1, p. 37). Chinese cotton, already known in the Japanese market, was of even poorer quality. Because of this problem, in 1889 the Osaka Spinning Company organized a mission to Bombay to study the Indian cotton spinning industry (the leading producer in Asia at the time). It then experimented with using Indian cotton. Here is an account given in the history of the firm of how the experiment went:

> "When the cotton arrived, it was so dusty and dirty and was so tightly pressed in thick layers that Yamanobe and others thought that it could not be used at all. … A special willow machine was ordered from England to separate the layers, remove the dust and grind the cotton before using it in the spinning mill. … the

results were excellent, and the superiority of Indian cotton was established beyond anyone's doubt." (Toyo Boseki, 1986, Vol. 1, p. 69)

Table 2. Technological Choice and Profitability Around 1884

	Number of spindles	Double shift	Source of power	Average profit per spindle (yen)
Osaka Spinning Company	10,500	Yes	Steam Engine	4.82
Average of all others	2,167	Only 1 firm	Only 5 firms	0.24
Of which:				
Mie	2,000	No	Water	-0.36
Tamashima	2,000	No	Steam Engine	1.53
Nagoya	4,000	No	Water	
Shibuya (Doshima)	3,000	No	Steam Engine	0.29
Hiroshima	2,000	No	Water	
Okayama	2,000	No	Steam Engine	
Himeji	3,000	No	Water	
Shimotsuke	1,000	No	Water	
Nagasaki	2,000	No	Steam Engine	
Toyoi (Yamato)	2,000	No	Water	0.64
Miyagi	2,000	No	Water	
Ichikawa (Watanabe)	2,000	No	Water	0.10
Shimada	2,000	No	Water	
Enshu	2,000	No	Water	
Aichi	2,000	No	Water	-1.18
Kuwahara	2,000	Yes	Water	0.49
Sakai (Kawasaki)	2,000	No	Water	0.44
Shimomura	2,000	No	Steam Engine	

Source: Calculated from the data in (Takamura, 1992, p. 112). Profits are three year averages for 1882-1884 for all firms but Osaka and Toyoi, for which they are two year averages for 1883-84.

Once adopted, this innovation spread instantaneously. While there had been virtually no imports of Indian cotton to Japan before late 1889, in 1890 Indian cotton accounted for 18.9% of ginned cotton purchased by the Japanese cotton spinning industry. In 1891 this share rose to 38.6% and then to 49.9% in 1892. American cotton of still higher quality followed soon.

Table 3. Technological Choice and Profitability Around 1889

	Number of spindles	Double shift	Source of power	Profit per spindle in 1889, yen
Osaka Spinning Company	47,060	Yes	Steam Engine	8.16
Average over all older firms	4,487	All but 1 firm	10 out of 17 firms	3.78
Average over older firms with steam engines	6,520			4.95
Tamashima	11,020	Yes	Steam Engine	9.25
Nagoya	9,000	Yes	Steam Engine	2.47
Shibuya (Doshima)	10,864	Yes	Steam Engine	0.76*
Hiroshima	7,000	Yes	Water and Steam	2.75
Okayama	4,824	Yes	Steam Engine	11.16
Himeji	4,752	Yes	Steam Engine	1.74
Shimotsuke	4,000	Yes	Water and Steam	8.09
Nagasaki	3,608	Yes	Steam Engine	
Toyoi (Yamato)	3,608	Yes	Water and Steam	4.42*
Miyagi	2,000	No	Water	
Ichikawa (Watanabe)	2,000	Yes	Water	
Shimada	2,000	Yes	Water	1.33*
Enshu	2,000	Yes	Water	3.30*
Aichi	2,000	Yes	Water	0.80
Kuwahara	2,000	Yes	Water	1.18*
Sakai (Kawasaki)	2,000	Yes	Water	1.76*
Shimomura	3,608	Yes	Steam Engine	3.92
Average over new entrants	9,898	All but 2 firms	All firms	4.76
Mie	16,222	Yes	Steam Engine	6.13
Tenma	14,797	No	Steam Engine	4.92
Owari	15,280	Yes	Steam Engine	3.37
Tokyo	9,104	Yes	Steam Engine	5.76
Kanegafuchi	16,744	Yes	Steam Engine	3.35
Naniwa	10,704	Yes	Steam Engine	
Hirano	4,992	Yes	Steam Engine	8.96
Fujii	1,136	Yes	Steam Engine	
Wakayama	5,524	No	Steam Engine	3.46
Kurashiki	4,472	Yes	Steam Engine	2.12

* Data for 1888. Source: Calculated from the data in (Takamura, 1992, p. 112) and in Geppo, January 1890.

OSAKA's pioneering and costly effort was compensated by a special "prize" the company received in the form of an exclusive contract with Tata Sons & Co. Under this contract, all other Japanese firms had to place their orders for imported Indian cotton through OSAKA (later through a trading firm closely linked to OSAKA), for a commission of 0.5% and 20% prepayment in cash. As far as we know this is the first documented case of an *ex post* transfer undertaken by an industrial association that worked in lieu of an *ex ante* subsidy to provide an additional incentive for innovative behavior.

The industry continued to grow rapidly at both extensive and intensive margins. By 1893 the number of firms had increased to 40, two years later to 65, and in 1899 the industry had 83 firms. The relative size of the Osaka Spinning Company progressively declined. In terms of spindles, its share in the industry total declined from over 22% in 1890 to less than 10% in 1895 to less than 5% in 1900. Its share of total output underwent similar changes. Instead, by the middle of the 1890s there were from five to six leading firms (including OSAKA) which altogether produced 40%-55% of the industry's total output.

Despite rapid growth, in the 1890s the industry remained not that large domestically, and internationally its presence was still negligible (Figure 1). In the early 1890s, imported cotton yarns still accounted for 50% of domestic consumption and imports exceeded exports until 1897. In terms of its effects on the input markets, the industry's share in total manufacturing output in Japan was still about half of the peak share of 8% it would reach in 1910-14, and its imports of raw cotton even from India were small enough not to be considered an important factor in determining the equilibrium price (eventually, as we will presently see, Japan would become the largest importer of raw cotton in the world). Thus even in the second half of 1890s modern cotton spinning sector as a whole was by and large a price taker in the input and output markets.

The strict "one leader and many followers" pattern of the early stage of development, however, was replaced by a few large firms which were more or less equals that led an industry filled with many more follower firms. Unlike OSAKA in the early stages of industrial development, the leading firms could reasonably expect to benefit from reciprocity. They were clearly aware that to enjoy the maximum benefits of sharing, no information should be concealed from other firms. As one foreign observer at the time put it, "Among the Japanese mills there are no secrets" (quoted in Otsuka, Rinis and Saxonhouse, 1988, p. 88).

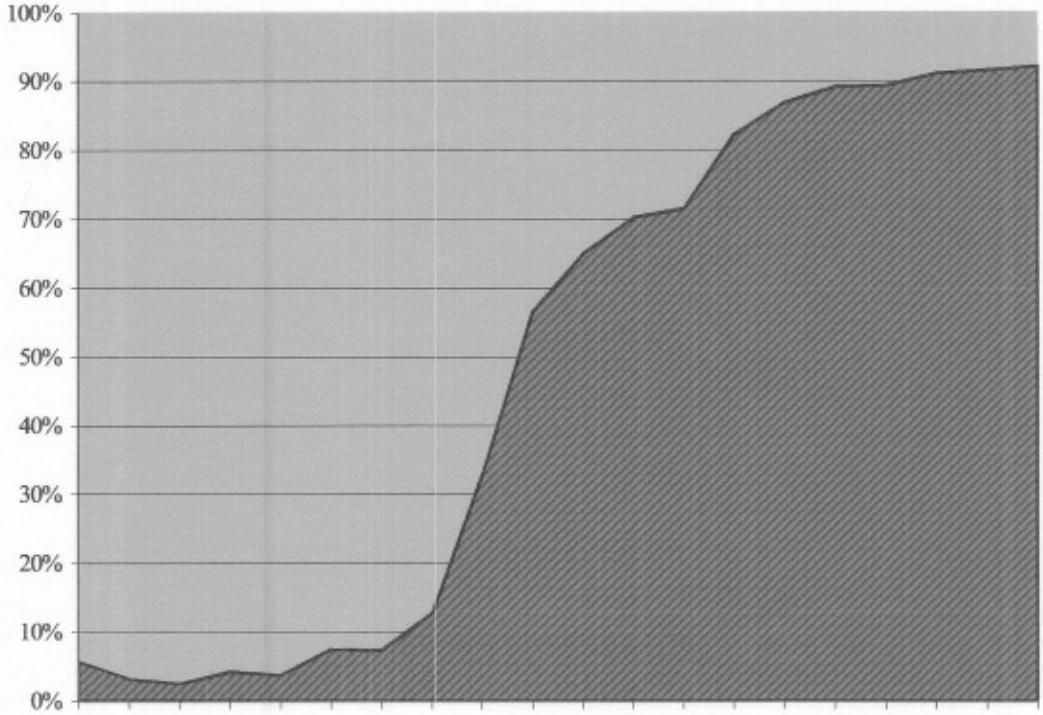
To foster mutually beneficial sharing of information about innovations, Japanese cotton spinning firms put in place a special institutional arrangement, the All Japan Cotton Spinners' Association (Boren). Technically, Boren was established under government auspices in 1886, but it was largely ineffectual until 1889 when its headquarters were moved onto OSAKA's premises and it was completely reorganized. From that time until well into the 20th century, Boren self-consciously attempted to mitigate the inherent free-rider problem associated with innovations that provide industry-wide spillover benefits. Its monthly bulletin contained detailed information on productivity and cost data collected from each firm, alongside with financial statements. The detailed technological data were often utilized in analytical articles written by the Boren staff and making explicit comparisons of efficiency across firms, which displayed a total "lack of feeling of confidentiality regarding these records" (Otsuka, Rannis and Saxonhouse, 1988, p. 87). The bulletin also paid a lot of attention to disseminating information about foreign technological and managerial innovations. Overall, 46% of its space was allocated to technical subjects from 1891 to 1900 (ibid., p. 89).

Boren did more than just provide a clearinghouse for information about new technologies. For example, its organization played a role in negotiating the aforementioned contract that OSAKA received from all other member firms as a reward for its effort to develop new raw cotton supplies from India. Many important technological decisions (for example, the decision to switch from mules to ring spinning frames in the early 1890s described immediately below) were debated at its regular meetings and the meetings of its board.

In addition to sharing information and devising mechanisms to reward innovative behavior, Japanese cotton spinning firms also shared technical personnel. Kyozo Kikuchi was a key person in bringing about a technological revolution in the industry in the 1890s, that of replacing mules with ring spinning frames. Ring spinning frame technology was developed in England but largely ignored there. Kikuchi, sent to England to study the cotton spinning technology immediately after joining the Hirano Cotton Spinning Company (HIRANO) (another instance of following OSAKA's example!), saw the advantages of the ring spinning frames in that they required much less skilled labor to operate. Thus the innovation in this case consisted of early recognition of the fact that a lower cost, lower skilled labor force in Japan conferred a comparative advantage to Japanese firms in the use of the ring spinning frame technology over England.

When HIRANO started operating, its 5,000-spindle mill consisted entirely of rings. Once again, what was learned was shared immediately, so diffusion was very fast: almost 100% of firms set up after 1890 installed only ring spindles, while the existing firms also revamped their old capital stocks quickly (Figure 2). This speed of ring diffusion in Japan was remarkable by world standards: in 1910 98.5% of the Japanese spinning frames were ring as compared to 82.4% in the United States, 51.6% in Russia, and only 16.6% in Great Britain (Saxonhouse and Wright, 1984, p. 280). The industry-wide switch to ring technology was the key ingredient in attaining international competitiveness. It should also be emphasized that the initial decision made by HIRANO was costly and somewhat controversial. In particular, OSAKA's Yamanobe was reported to have been very skeptical of this experiment.

Figure 2. Percentage of Ring Spinning Frames in the Total



Source: Otsuka, Rainis, and Saxonhouse, 1988.

Kikuchi's talents were immediately recognized by several leading firms. But instead of bidding for his sole services, three of those, Hirano, Amagasaki and Settsu Spinning Companies decided to jointly employ him as their chief engineer. The contract provided compensation to HIRANO from the two other firms for the money it had spent financing Kikuchi's study in England (Kinugawa, 1990, Vol. 4, p. 135). Such a sharing arrangement was an indication of the non-rivalrous nature of innovative activity given price taking in the output market. Kikuchi himself eventually sat on the board of seven firms.

Sharing of technological knowledge also took the form of training workers of newly established firms on the premises of industry leaders. At least 15 large-scale episodes in which one leading firm provided training to workers from other firms on its premises are documented in the 7-volume history of the industry (Kinugawa, 1990).[7] Although the immediate benefits to firms providing this training are not known (in particular, we do not know if any compensation was paid to them), it seems likely that at least part of the motivation was the desire to limit the raiding of trained workers. Kinugawa's (1990) 7-volume treatise on the early history of the Japanese cotton spinning industry presents numerous descriptions of bitter disputes over the raiding of workers, sometimes involving violence and at least once involving Boren boycotting one of its members for a whole year over alleged predatory practices in the labor market.

As it entered the 20th century, the industry had started outgrowing its infant stage. An early indication of its new status was the complete elimination of imports and the rise of exports to almost 40% of its total output (Figure 1). The industry suffered from its "first ever crisis caused by overproduction" around 1900-1901 (Takamura, 1971, Vol.2, p. 66-67). This was followed by a shake-out in which ultimately more than half of existing firms disappeared.

In the 1910s the ratio of cotton spinning output to total manufacturing output in Japan reached its peak level of 8-10%. By the 1920s the Japanese cotton textile firms consumed more raw cotton than the British industry; by the early 1930s the three largest cotton spinning firms in the world were all Japanese. In 1936, Japan had 10,595,000 spindles, behind only Great Britain and the U.S.A., with almost 7% of the world's total cotton spinning equipment. It consumed 3,649,000 bales of raw cotton per year (14.8% of world consumption), second only to the United States (Mitsubishi Economic Research Bureau, 1936, p. 235).

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[7] The Japanese firms also shared advisors from Platt Brothers of Oldham in largely the same manner (Saxonhouse, 1974, p. 162).

As an apparent result of these changes, the nature of cooperation among the firms also underwent a serious transformation. In particular, the industrial association (Boren) started leaning heavily toward a more conventional type of cartel, restricting the output of its member firms in order to try to prevent the price of the output from falling and prices of inputs from rising. The length and scale of output restrictions are presented in Table 4.

Table 4. Output Restrictions Imposed by Boren on its Members (1900-1912)

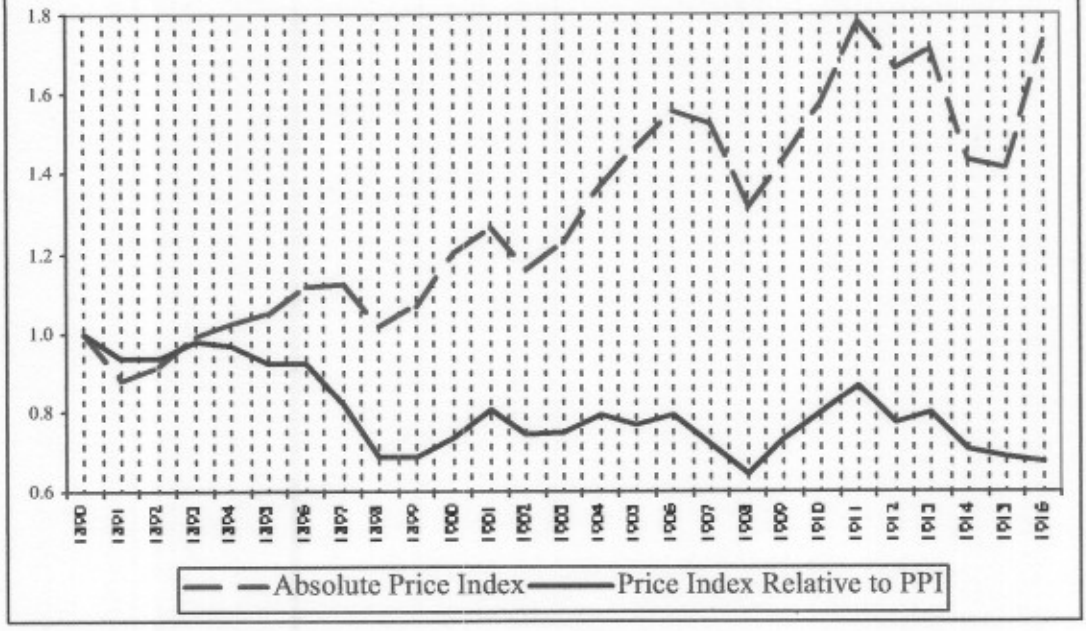
Periods of restriction	Counts 20 and below	Counts over 21
May 1900 - March 1901	4 mandatory holidays a month	No restriction
July 1902 - December 1902	Suspending night shift, or 40% idle capacity	No restriction
December 1908 - May 1909	5 mandatory holidays per month	No restriction
May 1909 - October 1909	Suspending night shift, or 27.5% idle capacity	No restriction
November 1909 - April 1910	Suspending night shift or 20% idle capacity	No restriction
October 1910 - March 1912	27.5% idle capacity, or (4 mandatory holidays per month + 2-hours break per day + 12.5% idle capacity)	20% idle capacity, or (5 mandatory holidays per month + 2-hour break per day)
April 1912 - September 1912	4 mandatory holidays a month	No restriction

Source: Takamura, 1971, Vol. 2, p. 175-176.

The restrictions clearly escalate over time, and become almost permanent toward the late 1900s. The enforcement of those self-imposed restrictions was also strengthened. Prior to 1908 Boren only sent periodic patrols to check the compliance with the restrictions. After 1908 the idling of capacity was enforced by sealing the essential parts of equipment (Takamura, 1971, Vol. 2, p. 175).[8] Notably, until 1910 the restrictions did not apply to higher (finer) counts of cotton yarns in which the supplies from the Japanese producers had been as yet a small fraction of total supplies to the Asian market. It is not clear if these measures helped prevent the decline in the output price although some authors have argued that it did. Figure 3, however, does not show much reaction to output restrictions.

[8] The need for such explicit enforcement mechanisms is not consistent with the popular suggestion that Japanese cooperation is more of a consequence of a cultural disposition for cooperation than a matter of incentives. Also note that as price taking waned, cooperation went from socially desirable efforts to accelerate technological adoption to collusive efforts to restrict output.

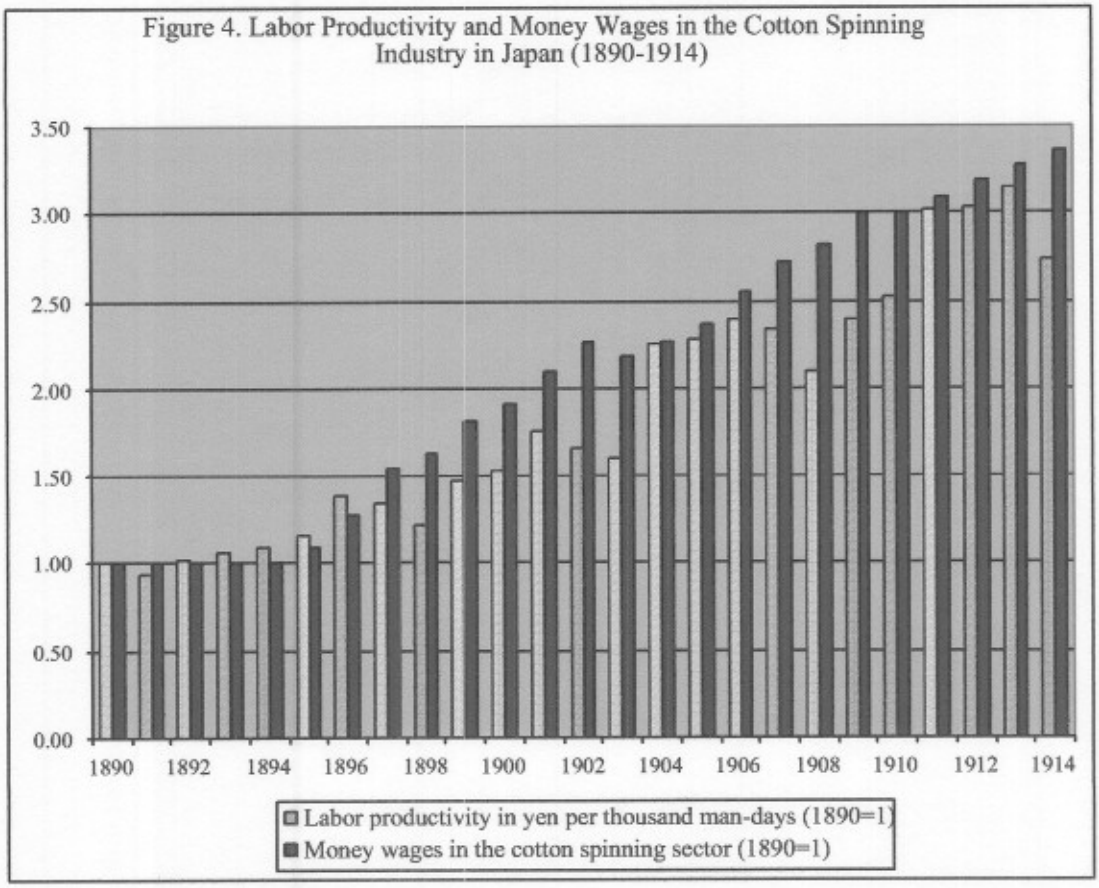
Figure 3.
Absolute and Relative Prices of Cotton Yarn



Source: calculated Ohkawa et al., eds., 1967-1979, Vols. 8, 11

Boren also tried to halt the rise in input prices, especially wages. It was clearly unsuccessful in these attempts as can be seen from comparing labor productivity to the average wage rate (Figure 4). Successful cooperation to effect efficient sharing did not automatically translate into successful efforts to effect collusion. However, it is remarkable that an increase in efforts to promote collusion coincided with the gradual demise of Boren's earlier role as the promoter of technological cooperation. For example, the allocation of space in Boren's journal to technical subjects declined from 46% in 1891-1900 to 18% in 1910-20 to 8% in 1920-1930 (Otsuka, Ranis, and Saxonhouse, 1988, p. 88-89). Detailed firm-level data were also gradually phased out, and we no longer have access to individual firms' physical input-output data after 1912. Platt engineers disappeared from Japan at the start of World War I never to return again.

Figure 4. Labor Productivity and Money Wages in the Cotton Spinning Industry in Japan (1890-1914)

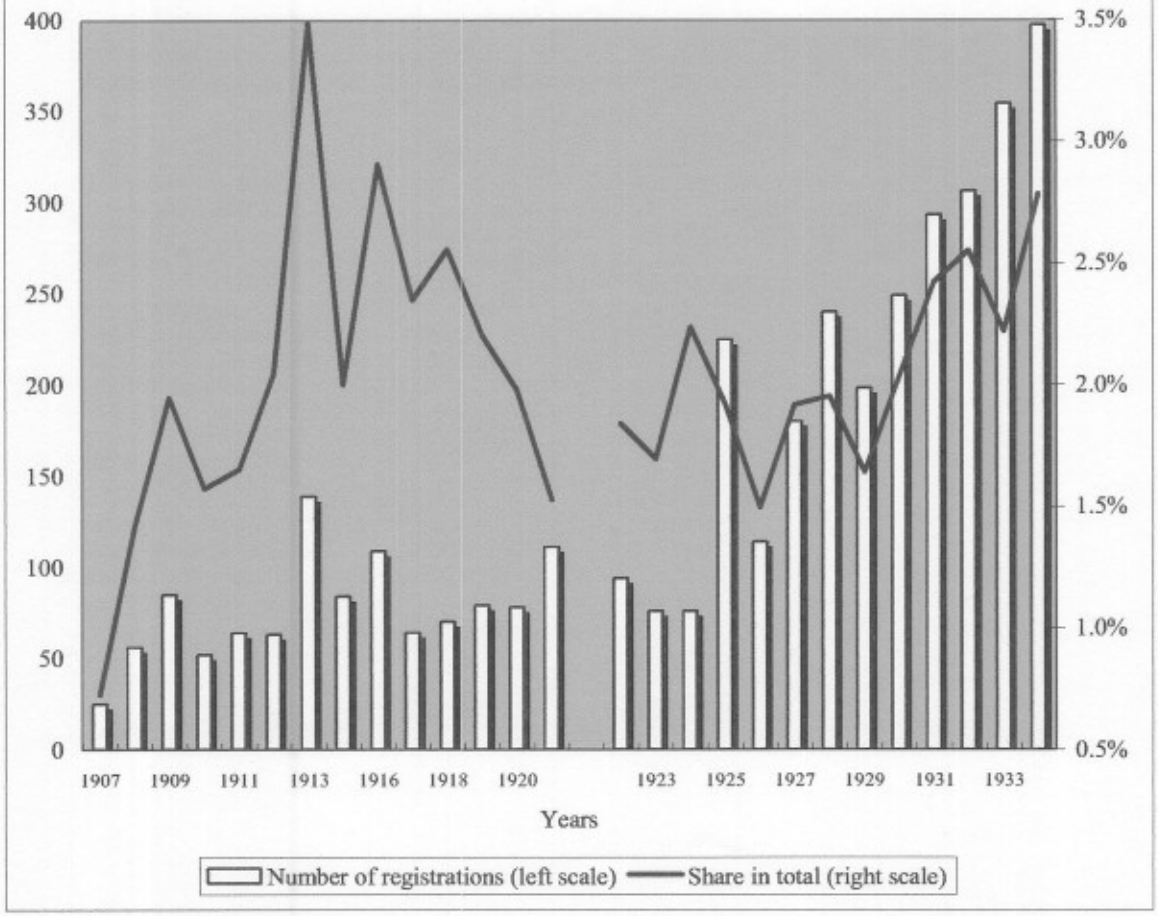


Source: calculated by the authors from the data in Ohkawa et al., eds., Vol. 11, 1979.

There was also a marked increase in attempts to singularly appropriate quasi-rents from the kind of innovations that would have been shared with other firms earlier. Figure 5 shows the number of cotton spinning-related utility models (petty patents) registered in 1907-1921 and 1922-1934 and their share in the total number of utility models registered. Both the number of registered utility models and their proportion clearly show an upward trend, growing by about 4 times over the 1907-1921 and 1922-1934 periods in absolute numbers and two times as a share in total from 1907 to 1921 and 1.5 times from 1922 to 1934. It is instructive to note that this increase in the share of utility models registered in cotton spinning (which is also observed in the share of its patents in total number of patents) happened during the period in which its share in total manufacturing output in Japan, if anything, exhibited a slightly declining trend from about 8% to about 7%. Thus it can be plausibly argued that the increase in utility models and patents was driven by a decline in intraindustry cooperation, not only by the growth of the relative size

of the industry. The one-time decline in the number of utility model registrations during the 1910s is also quite remarkable, since it followed the wave of mergers and the great increase in the sizes of leading firms – something which we argue in the theoretical model helps preserve cooperation.

Figure 5. Utility Models Registered in Fields Related to Cotton Spinning



Source: Compiled by the authors from the data in the Reports of the Imperial Patent Office for various years and in Kogyo Shoyuken Seido Hyakunenshi, Vol. 3.

From the point of view of the main topic of this paper, it is important to note that as the industry reached maturity, the innovators of the early infant-stage era who had been privately providing the public good for the industry were ultimately vindicated. During the 1900-1901

crisis especially, many firms that failed did so because they could not secure short-term bank loans to pay operating costs. Historical studies show that lenders clearly discriminated between firms that were widely perceived as innovative industry leaders and others when deciding on whether to give them access to credit lines (see, for example, Yamaguchi (1970)).

Moreover, the shakeout gave industry leaders a chance to cheaply acquire the production facilities of follower firms that were going bankrupt. Leading firms were thereby able to expand and establish even greater dominance over the industry as a whole. Case studies of mergers and acquisitions during the first two decades of the 20th century reveal that links established in the process of technological sharing during the infant industry stage, were among the most important factors determining acquisition matches (Kinugawa, 1990). We can interpret this evidence as telling us that sharing knowledge and other forms of technological assistance provided by industry leaders to lessor firms (as well as sharing between leaders themselves) were at least partly motivated by the desire to achieve better compatibility of organizational capital and other firm-specific factors in order to reduce the costs of future acquisitions and mergers.[9]

To summarize, then, in the earliest stage of development OSAKA acted as single, dominant-leader firm. OSAKA undertook virtually all investment in innovation while smaller firms (including new entrants) copied such innovations. OSAKA eagerly shared such information even as its market share fell. Eventually other firms became large so that the industry was led by a small group of large firms. The strict leader-follower pattern was replaced by a small set of large firms of equal influence surrounded by many smaller free-riding firms. Given the other large firms, there emerged benefits from reciprocity. Given the effect of free-riding on investment, there also existed an incentive to devise an institutional mechanism to drive-up investment up to its optimal level. The industrial association was clearly a conscious effort to address this problem, as were the other compensating mechanisms we have described.

[9] There were 68 cases of mergers and acquisitions recorded between 1902 and 1917. Sixty five of them involved unequal acquisitions, while three were equal mergers between industry leaders. See Ohyama, Braguinsky, and Murphy (2001).

IV. A Model of Cooperative Technological Adoption in an Infant Industry

A. *Case 1: Homogenous Firms*

We now present a model to exemplify the fundamental forces we believe were at work in the Japanese cotton spinning industry. To focus on the free-rider problem that results from sharing and the nonfirm-specific nature of innovations, in this subsection we consider the case of identical firms. To facilitate the analysis of the leader-follower relationship between firms and industry dynamics, in the next subsection we consider the case of firms that differ by size.

Consider an infant industry that is comprised of n identical firms. Firms are price takers in both the output and input market (we relax this assumption in Section VI). Industrial development results from the adoption of new technologies developed by more advanced countries. Let R be a measure of nonfirm-specific technological knowledge that is applicable to all firms in the infant industry. Firms must invest resources to learn of new technologies, to learn how to use them under local conditions, and to train workers in their use. The more that is invested in this process, the more frequent is the random arrival of innovations that increase the value of R. We assume that this increase is translated into factor-neutral cost-reduction as, for example, in Spence (1984). Formally, denoting the common cost function of all firms by $C(y,R)$ where y is for each firm's output, we assume that $C(0,R)=C_y(0,R)=0$, $C_y(y,R)>0, C_{yy}(y,R)>0$, while $C_R(y,R)<0$ and $C_{yR}(y,R)<0$ for all positive y. In words, the cost function is increasing and convex in output by each firm, and decreasing in the industry-wide stock of knowledge both overall and on the margin.

To examine incentives that lead firms to invest to generate increases in the industry-wide stock of knowledge in the simplest possible way, we employ a modified version of a patent race model due to Loury (1979). Let W denote the increase in a firm's profit that results from an increase in R.[10] Based on the discussion in Section II, we provisionally assume what will be derived as part of the equilibrium behavior below, namely, that there will be positive investment to generate new industry-wide knowledge and that such new knowledge will be shared with all other firms (that is, there will be perfect spillovers of innovations). Denote investment in generating R made by firm i by x_i. The variable x_i is expenditures incurred by firm i in its search for, experimentation with, and training of workers to use a new technology (or any other kind of

[10] The assumption that W is perpetual is based on our assumption that the infant industry possesses a comparative advantage in the use of the new technology.

innovation with industry-wide spillovers, including investment in human capital whose expertise is then shared among all firms, as described in the previous section). Let $\tau(x_i)$represent the date at which this investment will bear fruit and result in additional R. We assume that $\tau(x_i)$ is exponentially distributed with a linear hazard function hx_i.[11] The probability that W is realized by time period t by any firm i is therefore $\Pr[\tau(x_i) \leq t] = 1 - \exp[-hx_i t]$. In the simple non-cooperative Nash equilibrium the arrival processes are independent and at any time t the ith firm realizes an additional profit W in the event that either itself or some other firm has successfully completed the innovative project before that time. The probability of this event is $1 - \exp[-(a_i + hx_i)t]$, where $a_i = h\sum_{j \neq i} x_j$ is taken by firm i as given. Firm i's problem is then to choose a level of investment that maximizes its value: $\max_{x_i} \int_0^\infty W\left(1 - e^{-(hx_i + a_i)t}\right)e^{-\rho t} dt$, where ρ is the discount rate. This is equivalent to

$$\max_{x_i} \left\{ \frac{W(a_i + hx_i)}{\rho(a_i + \rho + hx_i)} - x_i \right\}. \tag{1}$$

The maximized function is globally concave in x_i, so the necessary and sufficient condition is:

$$\frac{Wh}{(a_i + \rho + hx_i)^2} = 1, \tag{2}$$

from which we obtain

$$\tilde{x}_i = \frac{\sqrt{Wh} - a_i - \rho}{h}. \tag{3}$$

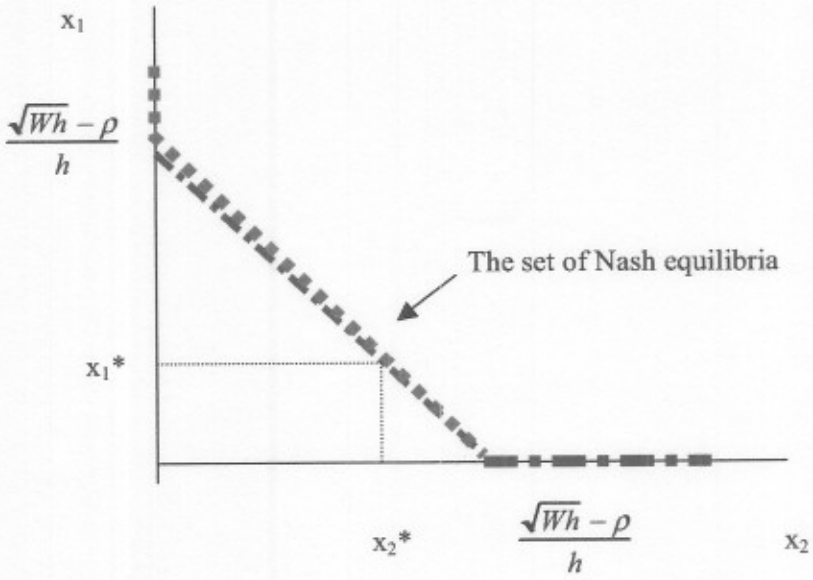
Clearly, firm i's optimal level of investment is a function of the level of investment selected by other firms. In Figure 6 we depict this relationship in terms of reactions functions for the case of two identical firms. These firms' reaction functions are identical 45-degree lines with the same intercepts, so there are infinitely many Nash equilibria, but the key point is that the total industry expenditure on innovative activity is always the same. Since all firms are identical, the symmetric Nash equilibrium in which all optimal $\tilde{x}_i$ are equal will be a natural focal point. In this focal point, the equilibrium values x^* for each of the n firms will be given by:

$$x^* = \frac{\sqrt{Wh} - \rho}{nh}. \tag{4}$$

[11] Assuming a non-linear hazard function $h(x)$ makes it impossible to derive an explicit solution, but leads to qualitatively similar results (see Loury, 1979).

From (4) it is easy to see that the optimal equilibrium investment level will be positive provided that the benefit of innovation W and return rate h are sufficiently high.

Figure 6. Nash Equilibria with Identical Firms



We can easily derive from (4) the following well-known properties of the uncoordinated Nash-equilibrium investment level: x^* will be increasing in the return to innovation W and will be decreasing in the discount rate as well as in the number of firms in the industry (in the fixed-cost specification of the knowledge-generating function we have adopted here). Substituting (4) into (1), given the assumption of symmetry in the Nash equilibrium, we obtain the value of a representative firm as:

$$V^* = \left(\sqrt{Wh} - \rho\right)\left(\frac{\sqrt{Wh}}{h\rho} - \frac{1}{nh}\right) \text{ with } \frac{\partial V^*}{\partial n} > 0. \qquad (5)$$

Intuitively, new entry reduces the waiting time until new techniques are discovered by some firm in the local group and therefore increases the value of each firm. In this sense there can be no long-run competitive equilibrium in this industry as long as firms in the local group are price takers in the global market. This is completely consistent with what happened in the Japanese cotton spinning industry – firms did not block entry but, instead, actually helped new firms achieve profitability but this abated as price taking waned.

It should also be clear from this intuition that sharing increases firm values in this environment. To see this, consider the case most likely to not result in sharing, the case in which

each firm can fully appropriate the fruit of its own learning regardless of whether it made the discovery earlier or later than any other firm (i.e., there are no patent races). Suppressing the index i, this "stand-alone" maximization problem can be written as $\max_x \left\{ \frac{Whx}{\rho(\rho + hx)} - x \right\}$, the solution to which is easily found to be given by $x_0 = \frac{\sqrt{Wh} - \rho}{h}$. The "stand-alone" value of the firm is thus equal to

$$V_0 = \left(\sqrt{Wh} - \rho\right)\left(\frac{\sqrt{Wh}}{h\rho} - \frac{1}{h}\right), \tag{6}$$

which is clearly less than (5) as long as $n > 1$.[12] The following proposition is the central theoretical result of our model in this section.

Proposition 1. Sharing new knowledge in a symmetric non-cooperative Nash equilibrium increases firm value in a price-taking infant industry. Moreover, investment in new knowledge will be positive as long as the return is sufficiently high regardless of whether firms share.

Proof: The first claim follows from comparing expressions (5) and (6). The second claim is established by noting that the numerator in (4) (the expression for x^*) is identical to the numerator in the expression for x_0. ■

The intuition behind Proposition 1 is simple. Firm values are increased by sharing because sharing reduces the waiting time before each firm gains access to new knowledge. Since the whole industry is a price taker in the global market, there is no reduction in the value of any innovation due to price competition, so only the beneficial effects of sharing matter.

Although sharing thus dominates concealing new information, it also makes possible free-riding which in turn results in an inefficient level of investment to generate new knowledge. To see this, note that since the industry as a whole acts as a price taker in the world market, neither the consumer surplus nor the prices of any other good in the home country (and in the world economy) are affected by increases in the supplies of n local firms in the infant industry. Thus the social surplus is exactly equal to the sum of surpluses earned by all firms operating in

[12] If there are patent races (an innovation completed by one firm precludes all other firms from using it and hence renders all their expenditure on the project useless), the stand-alone value will be further reduced.

the industry at a given time t, that is, it is equal to nW. Formally, given n, the social welfare is maximized at the point of $\max_x \left\{ \frac{Wnhx}{\rho(\rho + nhx)} - x \right\}$, or

$$x^{**} = \frac{\sqrt{Whn} - \rho}{nh}. \tag{7}$$

Comparing (4) and (7) it is clear that the socially optimal amount of investment, x^{**}, is greater than x^*, the privately optimal amount of investment.

To summarize, price taking gives rise to a Cournot-Nash equilibrium in which atomistic firms have incentives to invest in costly innovative activity and in which they do not have any incentives to conceal whatever they have learned from such activity from other firms even in the absence of overt coordination (Proposition 1). This implies that monopoly power in the output market is not a prerequisite for attaining innovation-led endogenous growth if the industry is open to global competition and is relatively small. The real problem confronting such an innovative process is free-riding, but we will show in Section V that this, too, can be resolved by private incentives. But before addressing this issue, we will briefly examine one more important uncoordinated equilibrium – the case of heterogeneous firms.

B. *Case 2: Heterogeneous Firms*

How is the basic model affected when firms differ in size? This is an important question because in the early stages of the development of the Japanese cotton spinning industry OSAKA dominated a number of smaller firms. To account for firm size differences in the simplest possible way we assume that firms are operated by entrepreneurs of different abilities A_i. Let the output of firm i be y_i, and its cost function be $C(y_i,R)/A_i$, where $C(y,R)$ is the same as before.[13] The underlying (common) cost function is divided by entrepreneurial ability, so higher ability makes it possible to attain a given level of output with lower average and marginal cost. The profit maximization problem for firm i becomes:

$$\max_{y_i} \left(py_i - C(y_i,R)/A_i \right), \tag{8}$$

from which we get

[13] The parameter A_i can be alternatively interpreted as a general measure of X-Efficiency or of "absorptive capacity" in the sense employed by Cohen and Levinthal (1990). In this case, the more X-Efficient (absorptive) firms are, the lower are their average and marginal costs and, as we will see, the larger they will be.

$$\hat{y}_i = C_y^{-1}(pA_i, R). \tag{9}$$

Clearly, $\partial \hat{y}_i / \partial A_i = p / C_{yy}(\cdot) > 0$, that is, the greater is entrepreneurial talent, the larger is the firm (see, for example, Murphy, Shleifer and Vishny, 1991).

The difference in the firm's flow of profit before and after the introduction of the innovation of the "size" dR is given by

$$W_i = \left(p\tilde{y}_i - C(\tilde{y}_i, R')/A_i\right) - \left(p\hat{y}_i - C(\hat{y}_i, R)/A_i\right), \tag{10}$$

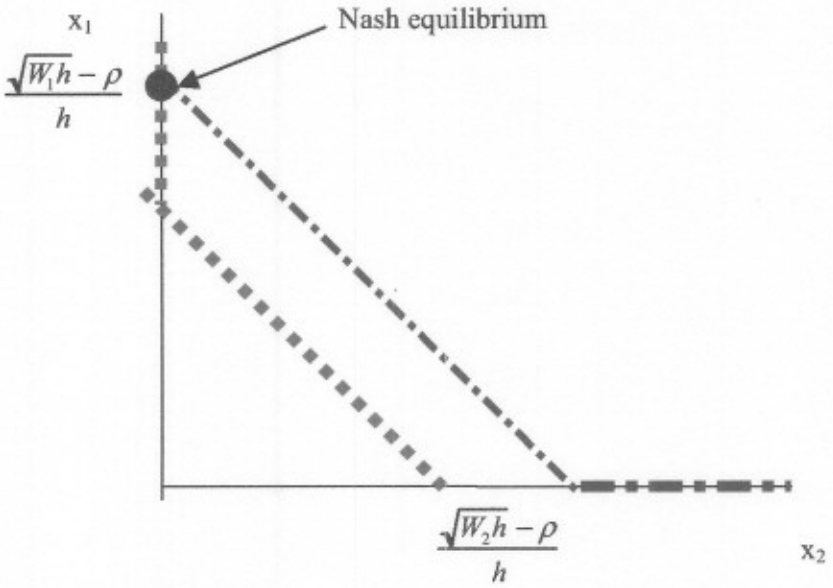
where $\tilde{y} > \hat{y}$ is the new optimal level of output corresponding to a higher level of industry-wide knowledge R'. Equations (9) and (10) imply that the gain from successful innovation is increasing with the size of the firm so that in accordance with our ordering of ability, $W_1 > W_2 > \ldots > W_n$.

Since each firm's investment in technology adoption is a perfect substitute for any other firm's investment given our assumption of a linear return function, the reaction function of each firm is still represented by a 45-degree line, but firm 1 (with the largest gain from innovation) will now have a higher intercept than any other firm. Thus the only Nash equilibrium will be the point at which firm 1 makes all the investment and no other firms make any investment at all (see Figure 7 for a geometric illustration in the case of two firms; see also Appendix A for a formal proof). This equilibrium level of investment by firm 1 will be given by

$$\tilde{x}_1 = \frac{\sqrt{W_1 h} - \rho}{h}. \tag{11}$$

Thus once we lift the assumption that firms in the local group are identical, we find that there is a unique Nash equilibrium in which only the largest firm will invest in generating the innovation while no other firm will invest at all. The value of this firms will be exactly equal to its stand-alone value V_0 defined by (6), while the values of all other firms will be higher. Given the assumption that the firm that generates new knowledge cannot extract any payments from other firms, this firm will at worst be indifferent between sharing and concealing. In practice, though, even small costs associated with concealing (like the threat of workers being raided) will be sufficient to induce sharing, so that Proposition 1 will continue to hold in a slightly modified form in this case of heterogeneous firms. Hence, largest firm(s) in our model, by investing to generate new knowledge, increase their own profits while producing spillovers on which smaller firms can free ride. In other words, we have an instance of private provision of a public good.

Figure 7. The Asymmetric Nash Equilibrium



V. Dealing with the Free-Rider Problem: the Neighboring Farmer Effect Revisited

The high speed of diffusion of the fruits of costly innovation is by no means a unique Japanese phenomenon. For example, Lerner and Tirole (2000) find significant capital investment in open source projects that is followed by very rapid diffusion that is basically free of charge to users. The question they ask, "Why should thousands of top-notch programmers contribute freely to the provision of a public good?" (p. 2) is exactly the same kind of question that a student of the Japanese cotton spinning industry more than 100 years ago would also have been compelled to ask.

Our first answer is based on the nature of a small industry facing what is, for all practical purposes, an infinitely elastic demand. As we have argued, such an environment in Japanese cotton spinning made diffusion harmless to innovators, because it did not reduce their sales and profits. Hence, even if obtaining intellectual property rights or keeping the new technology secret entails very small costs (which may not be true), there will be no incentives to incur those costs and diffusion will be immediate. This is a general lesson that seems to be particularly relevant for small industries (or local communities) just starting to develop.

The above is the essence of our Proposition 1 that established that sharing of new knowledge in the non-cooperative Nash equilibrium in (4) raises the value of each and every firm as compared to its stand-alone value. What makes things more difficult in securing the transition from a non-cooperative outcome in (4) to joint profit maximization implied by (7) which is clearly Pareto-superior to it, is that such an outcome requires coordination. Since the industry-wide benefits are not internalized by any particular innovator, our model in Section IV leads to the prediction that in the absence of coordination there will be underinvestment in innovation as compared to the first best in which spillover benefits are internalized.

We saw in Section III that Japanese firms found ways to internalize at least some of these positive externalities by means of a purely private incentive mechanism. Firms employed a mixture of "prizes" to innovators and a kind of a research cartel in the form of Boren. Moreover, we have argued that the environment of a developing industry populated by firms facing borrowing constraints creates strong private incentives to "signal" quality to potential lenders in which having a reputation for being an innovative industrial leader becomes a very valuable asset (this motivation of the Japanese cotton spinning firms may be similar to the motivation of "career concern" and securing future access to venture capital markets pointed out by Lerner and Tirole (2000, p. 14) with respect to open source software programmers).

All those diverse motives and mechanisms are examples of what we have called "the neighboring farmer effect." The essence of it is that common understanding of joint long-term interests promotes behavior according to which each member of a close-knit community does not necessarily insist on being perfectly compensated for what it has done for the common good but, instead, tends to think of the relationship with others as long-lasting and multiplex so that mutual debts have to be settled only in the long-run and even for such long-term settlement they just have to net out to zero across all "subaccounts."[14] If firms in an infant industry that is integrated into the global market are controlled by their own shareholders who understand the long-term prospects of the industry and are committed to staying in the industry, they are likely to develop relationships among them that will be very similar to neighboring farmers and that will allow them to resolve the free-rider problem in adoption-type learning quite effectively. But a note of caution is due here: there is nothing automatic about such a development and the actual

[14] See Ellickson (1991) for an extensive study, both empirical and theoretical, of such complex relations among neighboring ranchers in the Shasta county in California.

implementation of the cooperation induced by the neighboring farmer effect will largely depend on particular circumstances.[15]

The possible presence of private motives to internalize industry-wide benefits from innovative activity suggests that predictions about inter-firm cooperation at the R&D stage made in the literature on industrial organization can take very diverse forms. So far the forms of such cooperation that have been closely examined are industry-wide cooperative research agreements (Katz, 1986) or industry-wide research joint ventures (RJV) (Kamien et al., 1992). As we saw in Section III, Boren indeed played the role of such a research cartel in the Japanese cotton spinning industry. If the research cartel was the only possible mechanism for bringing about the socially optimal amount of innovative effort, then our model would predict that Boren would collect membership fees from firms sufficient to finance the innovative effort in the amount per firm given by (7), or in the total amount equal to

$$nx^{**} = \frac{\sqrt{Whn} - \rho}{h}. \qquad (7')$$

We do not have enough data to compare this theoretically predicted amount with the actual budget that Boren spent on collective investment to generate new knowledge although we do know that membership fees were collected and were used to finance joint missions to gather technological information and disseminate it through various publications, conferences, and so forth. We also know that a substantial number of innovations came from investments made independently by leading firms (see Section III). The fact that the Japanese firms did employ something like an R&D cartel solution speaks strongly in favor of the predictions coming from the existing literature, but the fact that it coexisted with the purely private provision of innovations suggests that this literature could be fruitfully extended by studying an optimal balance between how much R&D activity is organized in a joint-venture type business and how

[15] The Indian cotton textile industry had been the best-performing cotton textile industry in Asia until the Japanese industry overtook it at the turn of the 20th century. One of the main reasons for this reversal was that Indian cotton spinning mills lagged severely behind Japanese mills (and mills from other countries, including U.S. cotton spinning mills) in undertaking technological change (e.g., shift from mules to ring spinning frames) that occurred from the 1890s to early 1900s. One important cause for the failure of the Indian cotton spinning industry was the institution of managing agency which gave the decisive role in managing mills to minority shareholders running diversified businesses, many of them unrelated to cotton spinning and thus much less conscious of their joint interest as "neighboring farmers" in the cotton spinning industry itself (see Morris, 1965 for an extensive discussion of the managing agency system).

much of it is delegated to individual firms. We intend to pursue this topic further in our future research.

VI. Industrial Growth and the Breakdown of Cooperation

We saw in Section III that as the Japanese cotton spinning industry expanded, it also experienced a pronounced decline in inter-firm technological cooperation. In this section we show that our model is consistent with this evidence.

Cooperation results from the neighboring farmer effect, but this effect is ultimately based on price taking in the output and input markets. Both of these conditions will become less likely as the industry grows. Thus once account is taken of the general equilibrium repercussions of growth in industry size (both through the growth in the size of existing firms and from new entry), we naturally arrive at the conclusion that the more successful industrial development is, the more likely it is that the neighboring farmer effect will disappear.

We begin by considering the case in which the number of firms in the infant industry is fixed so that all the growth occurs through the expansion of existing firms in response to lower output costs brought about by successful innovations. Assume also that all firms are identical and, just to make things simpler, that there are no additional benefits from collusive forms of cooperative behavior such as price-fixing in the output and inputs market and preventing patent races.[16] Well-known results from the literature on cooperative R&D imply that full cooperation (for example, the RJV case considered in Kamien, Muller and Zang, 1992) will continue to dominate stand-alone innovation even though firms are now competing against each other in the output market (Proposition 2 in Kamien, Muller and Zang, 1992). The fact that local firms are expanding their global market share and squeezing out foreign firms by learning how to exploit their comparative advantage only makes cooperation even more attractive in our model.

To facilitate some simple analysis of this process, denote the inverse world demand function for output of the good by $p(Q)$, where Q refers to the total output of the global industry,

[16] The argument is easily adjusted to the cases in which there are costs to using the patent system or firms can also engage in cartel-like behavior. Both of these factors will raise the value of cooperative learning relative to the stand-alone value, so under such conditions cooperation will tend to last longer. Similarly, if there is a negative externality imposed by the race for a patent (see, for example, Loury, 1979), this will also lower the stand-alone value and the dissolution of cooperation will tend to be delayed.

$Q = Q_N + ny$, where Q_N is the output of all foreign firms. For a local innovation of the "size" dR the change in the world price is given by

$$\frac{dp}{dR} = p'(Q)\left(\frac{dQ_N}{dy} + n\right)\frac{dy}{dR} = \left(-\frac{1}{\varepsilon}\right)\left(\frac{p}{Q}\frac{dQ_N}{dy} + \frac{pS}{y}\right)\frac{dy}{dR}, \tag{12}$$

where $\varepsilon > 0$ is the price elasticity of demand and $S = ny/Q$ is the share of the local industry in the global output and where (see Appendix B)

$$\frac{dQ_N}{dy} = -\frac{(N-n)np'(Q)}{(N-n)p'(Q) - C_{yy}(y_f)}. \tag{13}$$

Here the symbol $C(\cdot)$ also denotes the cost function common to the N-n firms outside the local group but it is not a function of the local state of technology R. The variable, y_f, is the output of a representative "foreign" firm.

The increase in the expected (flow) value of a local firm in the cooperative equilibrium will be given by $(dp/dR)y + (p - C_y(y,R))dy/dR - C_R(y,R)$ or, upon substituting from (12) and (13) and taking account of the first-order conditions:

$$\frac{d\tilde{W}}{dR} = \left(\frac{1}{\varepsilon}\right)pS\left(\frac{(N-n)p'(Q)}{(N-n)p'(Q) - C_{yy}(y_f)} - 1\right)\frac{dy}{dR} - C_R(y,R), \tag{14}$$

where the expression for $dy/dR > 0$ is derived in Appendix B (see (18)).

Clearly, if the share of the industry in global output is sufficiently small (S is close to zero) the first term in the expression in (14) (which is negative in sign) is negligible so we have the "pure" neighboring farmer effect case. Only as S approaches one does this expression become similar to Kamien et al. (1992) and other closed-economy models. Thus as long as there are other competitors in the global industry who do not share the benefits of technological progress in the home country, the price-destruction effect of sharing innovations among the home country firms will be dampened, so that even with costless protection of intellectual property rights and perfect substitution among the products (the least favorable case to RJV considered in Kamien et al., 1992), home country firms will strictly prefer conducting cooperative learning through adoption to pursuing new knowledge separately even if patent protection was perfectly possible and not costly. This result is quite remarkable because it shows how persistent the neighboring farmer effect will be once it has emerged at an early stage of development. Incentives to cooperate will be weakened by growth, but they will not disappear as

long as the number of firms remains fixed. Also, since the spillover rate is at its maximum due to sharing, cooperative innovative effort results in a welfare-improving increase in resources spent on innovation, although the resources so expended will now fall short of social optimum even under the cooperative arrangement (Suzumura, 1992, Theorem 1).

The situation becomes completely different, however, when account is taken of the fact that the number of firms in the local industry will not remain fixed. Assuming that there is no way to exclude new local entrants from the cooperative sharing arrangement, the fall in the equilibrium price of output will be driven not only by the increase in the output of existing firms, but also by an increase in the number of firms.[17] It is the fact that any rents earned by existing firms are ultimately contestable by new entrants that finally destroys the neighboring farmer effect and explains why we do not observe voluntary sharing of technological information and/or R&D cartelization in most mature industries. In a reduced form, we can rewrite (14) above as follows:

$$\frac{dp}{dR} = p'(Q)\left(\frac{dQ_N}{dy} + n + n\delta\right)\frac{dy}{dR} - \left(-\frac{1}{\varepsilon}\right)\left(\frac{p}{Q}\frac{dQ_N}{dy} + \frac{p(1+\delta)S}{y}\right)\frac{dy}{dR} \Rightarrow$$

$$\frac{d\tilde{W}}{dR} = \left(\frac{1}{\varepsilon}\right)pS\left(\frac{(N-n)p'(Q)}{(N-n)p'(Q) - C_{yy}(y_f)} - 1 - \delta\right)\frac{dy}{dR} - C_R(y,R), \qquad (15)$$

where δ is the rate at which an innovation increases the number of local firms by triggering their entry and where for simplicity we take the incremental output of new entrants to be the same as the incremental output of existing local firms. If δ is sufficiently large, the first term in (15) will now definitely dominate the second as S grows from zero to one so that the price destruction effect will eventually exceed the beneficial effects from cooperation. Hence the stand-alone value will eventually become higher than the value of sharing and cooperation, at least if the country can establish a reasonably secure system of intellectual property rights protection. We can state this finding succinctly as

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[17] We have argued that such exclusion made no sense at an early stage of development when all firms were jointly price takers. However, here we are dealing with the situation in which the neighboring farmer effect is already waning. It is conceivable that existing firms, probably with the government's participation, would try to turn the industrial association into an exclusive R&D cartel and use the mechanism of intellectual property rights protection to prevent spillovers to new firms. We doubt that such an exclusive arrangement can be viable in the long-run in the context of our model. However, if it is, members of the exclusive R&D cartel will continue acting cooperatively as long as the arrangement is working. The situation will be exactly the same as analyzed in Kamien et al. (1992).

Proposition 2. Under free entry there will be some threshold size of the infant industry, S^*, after which the value of cooperative learning falls below its stand-alone value for each firm. Technological cooperation will therefore cease beyond S^*.

We do not give a formal proof of this proposition for it obviously requires specifying the dynamic process of new entry, including pinning down the factors that limit such entry by local firms in the first place all of which is beyond the scope of this paper. But the intuition is fairly straightforward, since in the long-run equilibrium with free entry the output price has to fall exactly in the same proportion as do costs, so that if the diffusion time is close to zero, then no innovator will be able to recoup the costs involved in generating new knowledge.[18]

It is important to stress that how large S^* will be in practice will depend on various factors, most crucially on whether the infant industry had been able to develop institutional arrangements that resolve the free-rider problem. Thus the success or failure in setting up an institutional arrangement for cooperative learning can be a significant factor that determines the ultimate success of an infant industry.

To summarize, then, firms in infant industries have a powerful incentive to cooperate with one another by sharing what they learn about new techniques and pooling their resources to communally fund information gathering as long the world price is unaffected by their actions. This cooperation socially desirable — it moves the equilibrium level of investment in such efforts closer to the social optimum. But a local group cannot grow *ad infinitum* without causing general equilibrium feedback effects in markets for both inputs and outputs. As price taking breaks down and free entry dissipates quasi-rents, the neighboring farmer effect wanes. Of course, this only happens well after the infant industry is no longer an infant industry. So the fading of the neighboring farmer effect is by itself a sure sign of successful industrial development.

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[18] Note that this definitely does not mean that erecting barriers to entry would be welfare-improving even though it may indeed help maintain cooperation among existing firms. With the local industry growing large and with intellectual property rights protection reducing uncontrollable spillovers, joint profit maximization by local firms is more likely to result in socially harmful curtailment of R&D investment as shown, for example, by Suzumura (1992). This is not to mention other potential welfare costs of restricting free entry.

VII. Conclusions and Policy Implications

Any less developed nation would be delighted to experience industry growth like that experienced by the Japanese cotton spinning industry at the end of the 19th century. The key question is whether the study of this industry might inform development policy today. The answer clearly depends on the extent to which the development of the Japanese cotton spinning industry was due to general and not idiosyncratic factors. By building a general model of how cooperation accelerates the adoption of new technologies developed by more advanced countries, one that is nevertheless consistent with the development history of modern Japanese cotton spinning, we have tried to make the case that the forces at work were indeed fairly fundamental and universal.

In the 1980s industrial planning was viewed by many as an example of Japanese exceptionalism that other countries, less developed and developed alike, would do well to emulate. Yet Japan's first example of industrialization was hardly an example of the value of industrial planning. The historical record shows that it was only after the government had abandoned industrial planning that the cotton spinning industry began an innovation-driven expansion, propelled by private incentives to cooperate in the process of searching for and learning how to use new technologies that are naturally present in an infant industry environment. The infant industry structure gives rise to the neighboring farmer effect which makes sharing privately optimal, greatly enhancing the speed of technological diffusion within the infant industry. The neighboring farmer effect also operates to increase investment in the kind of innovations that generate new industry-wide knowledge even closer to its efficient level. In our model, exposure to global competitive markets, not industrial planning, is what brings this powerful force into play.

The fact that the elasticity of demand plays an important role suggests that access to global market is especially important for small countries. A large country with a relatively deep output market (like the United States or some European countries in the 19th century) might not completely destroy incentives to share information even if access to foreign markets is very limited.[19] However, a small country with a small domestic market would be mistaken to adopt

[19] It can be argued that in a vast and heterogeneous country like the United States, there is always room for localized regional competition which can play the same role as free trade with the outside world does in our model to produce the positive effects we are concerned with here. One early manifestation of this is perhaps the development of the

such a policy. The Japanese experience that we have described in this paper therefore provides a much better guide for less developed countries.

The second general lesson to be learned from the Japanese experience of the late 19th to early 20th century is the importance of coordination mechanisms. The neighboring farmer effect is always potentially present in an infant industry exposed to global competition in the sense that each firm will find it *privately profitable* to invest in learning the best technologies developed in advanced countries. Without some kind of coordination, however, the value of spillovers benefits are not internalized so the resulting pace of adoption is sub-optimal. Although there are strong incentives for firms to come together and to resolve the free-rider problem in this environment (which is consistent with the theoretical literature on cooperative R&D), countries may differ in their ability to resolve this problem and some may fail to resolve it altogether because of bad government policies or some other defects of their institutional environments. Hence, we will observe firms in infant industries that have been able to resolve the free-rider problem more effectively to be learning through adoption more rapidly and for a longer period of time. In contrast, infant industries that for some reason fail to resolve the free-rider problem will tend to adopt new technologies more slowly and to end the practice of sharing earlier.

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Appendix A. Existence of a Unique Asymmetric Nash Equilibrium in Section IV.

Assume that firm 1 acts as if it knew that no other firm would invest in innovation. Its maximization problem can then be written as $\max_{x_1}\left\{\frac{W_1 h x_1}{\rho(\rho + h x_1)} - x_1\right\}$. Evaluating the first-order conditions and rearranging we obtain its optimal level of investment as:

$$\tilde{x}_1 = \frac{\sqrt{W_1 h} - \rho}{h}. \tag{16}$$

Given this investment level by firm 1, the second firm's problem is $\max_{x_2}\left\{\frac{W_2(hx_2 + h\tilde{x}_1)}{\rho(hx_2 + \rho + h\tilde{x}_1)} - x_2\right\}$ and its optimal level of investment x_2^* is given by $\max[\tilde{x}_2, 0]$, where $\tilde{x}_2$ is obtained by taking first order conditions of the firm 2 optimization program and substituting from (11):

$$\tilde{x}_2 = \frac{\sqrt{W_2 h} - \sqrt{W_1 h}}{h}. \tag{17}$$

Since $W_2 < W_1$ by assumption, $\tilde{x}_2 < 0$. Thus we conclude that $x_2^* = 0$, so that firm 2 (the second largest one) will not invest in innovation given the optimal choice of firm 1. This *a fortiori* holds for firms 3, …,n of even smaller sizes, so the situation in which firm 1 bases its actions on the

assumption that no other firm will invest is indeed a Nash equilibrium. It is easy to check that this equilibrium is also unique.

Appendix B. Local versus Foreign Firms in Section VI.*

Since all firms act as price takers when choosing their amounts of output, the *n* firms in the infant industry will choose their output levels after the innovation so as to satisfy $p = C_y(y, R)$, while *N-n* other firms in the global industry whose cost functions do not change will choose their output levels so as to have $p = C_y(y_f)$. Totally differentiating these first order conditions we obtain a system of equations

$$p'(Q)(N-n)\frac{dy_f}{dR} + \left[p'(Q)n - C_{yy}(y,R)\right]\frac{dy}{dR} = C_{yR}(y,R)$$

$$\left[p'(Q)(N-n) - C_{yy}(y_f)\right]\frac{dy_f}{dR} + p'(Q)n\frac{dy}{dR} = 0$$

solving which for dy_f/dR and dy/dR we get

$$\frac{dy}{dR} = \frac{p'(Q)(N-n)C_{yR}(y,R) + C_{yR}(y,R)C_{yy}(y_f)}{\Delta} > 0,$$

$$\frac{dy_f}{dR} = \frac{p'(Q)nC_{yR}(y,R)}{\Delta} < 0 \qquad (18)$$

where $\Delta = p'(Q)(N-n)C_{yy}(y,R) + p'(Q)nC_{yy}(y_f) - C_{yR}(y,R)C_{yy}(y_f)$ by the second-order condition. For signing the numerators of (18), recall that we have assumed that marginal costs are increasing in *y* but decreasing in *R*, that is, $C_{yy} > 0$ and $C_{yR} < 0$. From (18) we obtain (13):

$$\frac{dQ_N}{dy} = (N-n)\left(\frac{dy_f}{dR}\Big/\frac{dy}{dR}\right) - -\frac{(N-n)np'(Q)}{(N-n)p'(Q) - C_{yy}(y_f)}.$$

Note that when *N* is large as compared to *n*, the limit of this expression is equal to *-n*, so that from (12) we see that the world price indeed does not change in response to a successful innovation in the infant industry. On the other hand, when *n=N* (the infant industry has grown to squeeze out all its foreign competitors), we have the situation analyzed in Kamien et al. (1992) and other similar models.

* We owe some of these derivations to Francisco Buera.