TECHNICAL ADAPTATIONS AND MANAGERIAL RESOURCES IN INDIA: A STUDY OF THE EXPERIENCE OF THE COTTON TEXTILE INDUSTRY FROM A COMPARATIVE VIEWPOINT

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I. ANALYTICAL SCOPE

As is well known, India was the earliest country in Asia to start her industrialization. From the 1830s modern technology for mass production was gradually and steadily transplanted from European countries, especially Great Britain. The cotton textile and jute industries were the most typical examples of such technological transfers which had brought to India a completely new system of management and labor organization as well as novel experience of machine operation. Nevertheless, in the case of the cotton textile industry, such a new factory system was already firmly rooted by the 1870s under the combination of Indian capital and British technical cadres.

The tentative success of transplanting the new system was manifested in the huge amount of Indian coarse yarn that was being exported to the Chinese market in the 1880s and 1890s. This was partly a reflection of the advantage, in terms of cheap labor and geographical location, enjoyed by the first country to begin to industrialize in Asia. However, as early as the turn of the century the Indian cotton textile industry had begun to lose its international competitive power in the Chinese market, mainly because of the rapid growth of a newcomer, the Japanese cotton textile industry. In subsequent years India had furthermore to suffer from the threat of losing even her domestic market for cotton yarn and fabrics as a result of competition from the Japanese and Chinese cotton textile industries.

Why did the Indian cotton textile industry so quickly lose its competitive power in the international market? This is the problem we should like to answer in this paper, and it is also a problem which must be solved in order to understand the recent technological stagnancy of the Indian economy despite the solid outward appearance of its manufacturing industry. Up to now, various

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approaches to this problem have already pointed out its major causes, such as the failure to modernize technology, poor entrepreneurship, lack of labor discipline, exploitation under British rule, etc. Most of these views cannot in fact be denied, but they have not yet fully analyzed the deeper reasons for them. That is to say, the following questions remain to be answered: Why did the Indian economy fail to keep its technology up-to-date? In what senses and in which areas was entrepreneurship actually poor and was the Indian economy practically exploited by Great Britain? Here we shall try to answer these questions from the viewpoint of managerial resources in India within the context of the problem raised above.

For this purpose, the role played by European technicians, the social backgrounds of directors, the development of technical education, etc., must be examined in detail in relation to the process of decision-making in actual cases of technological adaptations. Hence we will first confirm in Section II the fact that responses to new inventions in textile technology were considerably slow by checking the approximate dates of the introduction and adoption of some epochal innovations against the supporting evidence from the information contained in the *Indian Textile Journal*. In addition, the diffusion speed of a new spinning machine and the regional variation in its adaptation pattern will be statistically discussed in greater detail. To explain these differences by region, the historical background of the high dependence on foreign technicians and the slow development of technical education are examined in Section III. This reveals the important role of foreign managerial staff in decision-making related to technological choice in the face of poor managementship by Indian directors.

The period under consideration is the fifty years from 1890 to 1940. Our appraisals on technological adaptations and managerial decisions in the Indian mills are based upon an implicit comparison with the Japanese experience, which can be regarded as a relatively successful example in the sense that the large-scale transfer of foreign technology was well-adapted to her domestic markets through active entrepreneurship and intensive educational investment. To approach the problems objectively, our discussion contains some quantitative analysis, namely, a regression analysis and log-linear model analysis of the contingency table. This, however, is confined to the problem of the replacement of Mules by Ring frames because of data-availability limitations.

II. THE SLOW DIFFUSION OF NEW TECHNOLOGIES

A. *Responses to New Technologies*

1. *Two kinds of information route*

In the planning of erecting a new plant or purchasing a set of machinery for it, it is first necessary to obtain adequate information on the functions, characteristics, qualities, and prices of various brands of machines. In general, there exist two different kinds of information source which can be used to evaluate those aspects of machines, namely, the so-called "human-embodied" type and the "human-disembodied" type. Examples of the former are information based upon the actual experience of textile engineers or information directly provided by machine-makers, etc., whereas examples of the latter are professional journals or handbooks on textile machinery, advertising pamphlets by machine-makers, manuals for machine operation, etc.

One of the unique characteristics of the Indian cotton textile industry, compared with the Japanese experience, was the much higher priority on human-embodied sources of information for the acquisition of new information on textile technology. This information route is usually more subjective, more conservative, and narrower as regards the possibilities of machine selection than is the other, especially from the long-run viewpoint. It is, however, a very convenient and also reliable way, whenever (1) the planner himself has not enough knowledge to judge new information, and (2) the information provider is a technologically trustworthy person. In India the first of these two conditions was almost always the case, but whether the second one was equally satisfied is to be doubted.

Most of the managing agencies of mills usually had rather close contact with agents of textile machinery makers in Bombay. In some cases, the managing agency even served concurrently as the machine-maker's agent.[1] However, the information provided by a machine-maker was naturally based upon the aim of sales promotion, so that it was risky for the planner to accept the raw suggestions from a maker without referring to any further possibilities. Thus consultations with the technical cadres in one's own mill occupied an extremely important role in the case of technological choices in the Indian cotton textile industry.

As has often been pointed out, not a few of these technical mill staff were nevertheless "ineligible" for such consultations for one of the following reasons. (1) A majority of the posts requiring technological knowledge had been occupied by British technicians, especially in the nineteenth century, and a large number of those technicians had come to India through the good offices of textile machinery makers. They thus had special connections with the makers, and hence became actually a sort of makers' agents in India, when the mills they were working for planned to replace old machines or to extend the plants. (2) On the other hand, not a few of those technicians who were not connected with machinery makers were also said to have only quite limited knowledge of textile technology, based mainly upon their working experiences in the home country. Their knowledge was accordingly up-to-date only so long as British textile technology was leading the world textile industry. Thus it can be said that the first kind of information route was convenient and efficient especially at the initial stage of transplanting the modern cotton textile technology to India, but that this was not necessarily true for subsequent years. At any rate, this seems to have been the main route for acquiring information on new technology in India,

[1] Greaves, Cotton & Co., Bradbury, Brady & Co., Nawrojee Wadia & Sons, MacBeth Bros. & Co., Marshall, etc., are well known as such dual agents.

mainly due to the inability of directors and owners to make technological decisions for themselves.

The second route of information is in general more objective and more comprehensive than the first route, assuming a decision-maker can rather easily gain access to various kinds of information and has sufficient ability to judge such information. In those days the quickest route to comprehensive information was probably the professional journals on the textile industry, such as *Textile Machinery, Textile Manufacturer, Textile Mercury, Textile Recorder,* etc. Machinery exhibitions or trade fairs must also have been quite helpful in diffusing new technologies, but these were not continuous sources of information. The circulations of these periodicals are said to have been very small, although the language barrier in India was not so high as in the case of Japan.

It was in 1890 that the *Indian Textile Journal* was established for the purpose of diffusing exact and comprehensive information on textile technology and commerce throughout the whole country.[2] The enlightening effect of the *Journal* is admitted to have been enormous. Specifically, it is claimed that the *Indian Textile Journal* had great influence on the introduction of new technologies, and was almost the sole influential source of the latest technological information in India, at least up to around 1920.[3] It should also be pointed out that the *Journal* was an eager promoter of the introduction of new textile technologies, as well as an advocate of rational management and higher technical education. For instance, it was famous for its firm stand on Ring spinning frames and the construction of the Tata hydroelectric power supply system. The *Journal* was liberal and equally open to every argument or conservatist position against such innovations. Hence we can observe many of the interesting controversies in the period in the *Journal*. These are the reasons we analyze the frequency of articles on major textile inventions appearing in the *Indian Textile Journal* in the next section to grasp the stream of technological adaptations to new inventions in the cotton textile industry.

2. *Introduction of information on new technologies*

Every issue of the *Indian Textile Journal* contained the latest information on the world textile industry as well as the Indian one, under the various headings of editorials, general articles, commercial reports and trade notes, reviews of books and catalogues, etc. Although some parts of them were reproductions from other journals in different countries, for this very reason it was a convenient and up-to-date source of information. The most useful information on textile technology was contained in the machinery guides, "Machinery & Appliances,"

[2] We have no exact information about its circulation figures, but it has been said that at the initial stage it already published at least 500 copies.

[3] This might be thought to follow the British tradition in the sense that in Britain technological information was provided, not by such industrial organizations as the millowners' association, but by independent institutions. This shows a sharp contrast with the Japanese experience where the All Japan Cotton Spinners' Association often took a positive role in encouraging the introduction of new technologies.

"Recent Improvement in Textile Machinery," etc., which were essentially advertisements by the machinery makers, but had a large enlightenment effect through the presentation of the latest technological progress.

To understand when and how the hot discussions about the major textile inventions arose in the Indian cotton textile industry, we feel general articles on those issues are preferable to the above-mentioned machinery guides, since the latter were often biased by sales promotion policies. Here we pick out several epochal inventions discussed in the issues between Vol. 1, No. 1 (October 1890) and Vol. 47, No. 3 (December 1936),[4] and briefly confirm when they were introduced and how they were evaluated in the *Journal*.

(1) One of the remarkable improvements in nineteenth century textile technology was the invention of the revolving flat card. It was finally completed around 1857 by Even Leigh. The superiority of the revolving flat card over the previous roller card was already well known to the Indian industry at the time of the *Journal*'s establishment.[5] Probably this was the main reason why the significance of the new system was discussed in articles only during the first few years of the 1890s.

(2) The spinning section, as a final process, occupies at least one-third of the entire machinery in a textile mill. Hence technical progress in spinning frames has a crucial effect, and even a slight improvement in them leads to a great increase in productivity as a whole. In this regard, the appearance of a new spinning machine, the Ring frame, in the 1830s prepared a revolution in spinning technology in general in subsequent years. The perfection of the Rabbeth-Sawyer type of Ring frame in the 1870s led to its rapid diffusion in place of Mule spindles in various countries except for Great Britain and India. The reasons for its slow diffusion in India will be examined in detail in the following sections.

The controversy over the relative advantages of Mule and Ring was one of the central issues in the *Indian Textile Journal* from the beginning of its publication. However, the controversy was in effect concluded around the mid-1890s when it was agreed that Ring frames were more appropriate than Mule spindles in the Indian cotton textile industry. Nevertheless the actual adoption of Ring frames was slow and gradual except in its initial stages. Thereafter introductions to both types of spindles continued in the *Journal*, since both the Mule and Ring were considerably improved in the 1910s and 1920s, respectively.

(3) Another great controversy in the *Journal* was focused on the relative

4 The issues Vol. 28, No. 5 to Vol. 29, No. 3 (February to December 1918) are not included because of their unavailability. The author would like to express his deep thanks to Dr. Kenji Koike for his kind cooperation in providing access to the *Journal*.

5 Carding is one of the most important processes in cotton spinning, since it essentially determines the quality of the yarn. To produce quality yarn or purposive counts, the accuracy of a carding engine and its system is decisive. Uniformity, simplicity, or flexibility of the system, space saving, and durability are also desirable characteristics. With respect to all of these properties, the revolving flat card engine was superior to the roller and clearer card, and was thus ultimately more economical in spite of its higher price.

merits, as the means of power transmission, of the electrical drive and the mechanical drive, i.e., driving by geared shafts.[6] As early as 1892 the advantages of the electric drive were already being emphasized on the basis of European experience. This was an extremely early advocacy when we remind ourselves of the strong conservatism and reluctance to undertake electrification in Great Britain. It can be interpreted as a reflection of the *Journal*'s progressive editorial stand. During the period 1907 to 1909 economic arguments on electrification were being enthusiastically fought by its advocates and antagonists.[7] Their discussions seem to have included a certain amount of ambiguity, since the functions of the electric motor for power transmission and of the dynamo for power generation were often jointly argued.

In 1910, however, the license for electric power supply in Bombay was given to the Tata Co., and Tata Hydro-electric Power Supply Co. started to supply electric power to Bombay mills in 1915. This epochal undertaking greatly reduced the likelihood of adoption of the dynamo (alternator) for private power generating plants, at least so long as power could be purchased from the station cheaply. Thus in subsequent years the main discussion was shifted to the problems of the individual drive and various other matters, but the total number of articles on electrification in the broad sense amounted to one-fourth of all technological articles in the *Journal* between 1890 and 1937. That is to say, it was one of the principal fields in which the *Journal* tried to promote the modernization of Indian textile technology. We may conclude that its contribution was not small as, for example, in the case of its firm support for the Tata hydro-electric power supply scheme against strong opposition.

(4) In connection with electrification, the problem of choice of prime movers was also argued extensively, especially around 1909. The alternatives were steam engines, steam turbines, gas engines, Diesel oil engines, and also dynamos. From the economic viewpoint, the dynamo as a prime mover was somewhat questionable, although its smaller size must have made it sufficiently economic for electric lighting. Most of the cost estimates suggested the steam turbine as the best power generator.[8] The choice of prime movers was a matter of some importance, espe-

[6] Here "mechanical drive" refers broadly to the geared wheel drive, the belt drive, the rope drive, and the chain drive. Note that in the case of electric motors, the power is transmitted from a motor-driven shaft to machines through belt or rope only at the final stage, that is, the essence of an electric drive is the decentralization of power. Among different methods of mechanical transmission in India, the rope drive had gradually become the main current, replacing the belt drive after the beginning of the twentieth century.

[7] Compared with the mechanical drive, generally accepted advantages of the electric drive were the following: smaller loss of transmission power (about 10 per cent less); simpler and lighter shafting and gearing; greater steadiness of drive; higher flexibility for extensive and independent operation (e.g., local overtime operation); greater uniformity of machine speed; and greater adaptability in the layout of machines. These benefits were realized mainly as a result of rapid improvements in electric motors at the end of the nineteenth century. There still remained some scepticism and reluctance to switch over to the new system on the part of the conservatives.

[8] Such cost calculations for Indian situations are found, for example, in the issues of January, April, May, June, October, and November 1909, December 1928, and January and June 1932.

cially before the hydroelectric power network was established. Even thereafter its significance was not greatly reduced, since the private power generating plant was still the only possible economical system for many mills. Thus this problem was intermittently discussed in the *Journal* in subsequent years as well.

(5) At the next stage of development in electrification, the keenest arguments centered on the economic advantages of the individual vs. group drive of textile machinery by electric motors. The first encouragement for individual drive can be found as early as 1908,[9] and heated discussion developed around 1913. The main issues in the argument were concerned with the authenticity of the output increase brought about by individual drive, the most appropriate sections for individual drive adoption, and the suitability of group drive in the case of remodellings of old plants. The peculiar conditions of Indian industries were almost always emphasized by those satisfied with the status quo, to oppose the individual drive. But it is worth noting that their views resembled quite closely those expressed in similar discussions held in Great Britain.

(6) Adoption of the power loom had greatly contributed to the increase in labor productivity, and the invention of an automatic power loom brought on a further leap of production in the weaving industry of various countries. The well-known Northrop automatic loom was invented in 1889 by an Englishman, J. H. Northrop, and started to be produced in 1895 on a commercial basis by a U.S. firm, the Draper Co. The *Indian Textile Journal* introduced the Northrop loom in its machinery guide as early as December 1895. In subsequent years various brands of different types were intermittently introduced,[10] but, in general, more attention was paid to the power loom than to the automatic loom. It was not until the year 1931 that the adoption of the latter was seriously discussed as a means of surviving the Great Depression. Even then, the incompetence and low productivity of Indian labor were emphasized to excuse its slow diffusion.

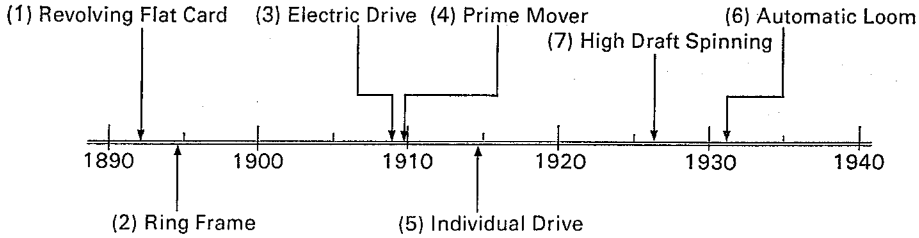
(7) The 1920s marked the dawn of a new era for textile technology. The first great innovation to be diffused was the epochal system of High Draft spinning, of which the prototype was invented in 1904 (first shown in 1913) by a Spanish, F. Casablanca, and had completed its experimental stage by 1921. The first article on the High Draft system appeared in the *Indian Txtile Journal* of 1926, at a time when it had already realized vast diffusion in European countries.[11] In the next year more intensive discussions took place as to the superiority

9 Among the numerous advantages of an individual drive, the following were considered to be relatively great: smaller cost of mill-erection, distinct reduction in power consumption, localization of breakdowns, and increased quality of output. The weaving shed and the Ring spinning section were said to be the most suitable places for the individual drive.

10 The Northrop loom was a so-called bobbin-changing loom, and so was the Whittaker. The Hattersley, the Vickers, and the Toyoda looms were of a shuttle-changing type. Although each type had its own merits, and their productivities did not differ much, the Northrop loom was the best-known in India.

11 Around 1927, no less than a dozen different High Draft spinning systems existed, known as the systems of Casablanca, Ferrand, Toenmiessen, Howard & Bullough, Platts, etc. But their divergent principles really boiled down to only four basic systems: Casablanca, Four Roller, Three Roller, and Apron (improved Casablanca). The Apron system and its variations were very popular in Japan, and the Casablanca in Bombay.

Fig. 1. Modal Years of Articles on Major Innovations Appearing in the *Indian Textile Journal*



of different High Draft systems and their adaptation to Indian conditions, viz., low-quality Indian cotton and inefficient labor. These problems were continually studied in connection with various types of machines in the 1930s.

(8) Many other branches of textile technology also enjoyed rapid progress in and after the 1920s. In spindle driving, for instance, a new method, the tape drive, became popular and was introduced in the *Journal* in 1927. This could be regarded as a much improved method of driving over the existing band drive with respect to uniformity of twist, speed of spindles, and ease of upkeep. These advantages continued to be maintained in the 1930s against opposition from the conservatives. Dyeing methods also progressed a lot in the 1920s. German chemical dyes were coming to prevail, and cheese-dyeing instead of warp-dyeing was strongly recommended in the *Journal*. Sizing machines were also improved in various ways. The indispensability of a humidifier, e.g., a Carrier system, in mills was theoretically confirmed. In the winding and warping sections, the adoption of high-speed machines of different brands was encouraged through various advertisements in the *Journal*. Thus it can be seen that the *Indian Textile Journal* was continuously providing new information on textile technological innovations,[12] and urging the realization of rational management through the introduction of high productivity machines. The main part of our discussion so far is summarized as Figure 1.

3. *Slow adoptions and British influences*

From the above evidence, we may point out two characteristics of the introduction of new technological information by the *Indian Textile Journal*. First, the introduction of innovational information came rather early, compared with the experiences of other non-Western countries. This was almost wholly due to the firm ties of the Indian cotton textile industry with the British industries. Secondly, as the result of such close ties the information was greatly affected by movements within the British textile industry. The various appraisals of new inventions were always British-experience-oriented. Thus, despite the sincere

12 Some other inventions such as the precision winder, the Nathmith comber, etc., were also very important improvements, but their significance to the Indian industry was not so great, since almost all production in the Indian cotton textile industry was of coarse yarns.

endeavor by the *Indian Textile Journal,* the information circulated within the Indian cotton textile industry was apt to be biased and subject to the British experience.[13]

In other words, the second "disembodied" route of information as well as the first "human-embodied" information was also indirectly ruled by the British industries. This kind of monopoly in information could be seen as the result of British colonial rule. Yet while this cannot be denied, it does not tell the whole of the story. We cannot avoid touching upon the problems of the recipients of such information. Their attitudes towards technological information were in sharp contrast to the Japanese experience, as may be inferred from what we have already discussed. Before closely examining those facts and the underlying reasons, we will briefly review the actual adoption of major inventions in the Indian cotton textile industry.

As statistical data on the diffusion processes of the above mentioned new machines are not available at all, except in the case of Ring frames, we have to content ourselves with rough impressions on the diffusion speed gleaned from fragmental data.[14] As for the revolving flat card, the first Indian introduction of a flat carding engine took place in 1885. After that, imported carding machines were mostly of the new revolving flat type, but the diffusion speed was fairly slow. By contrast, the diffusion rate of the revolving flat card was quite high in Europe and the United States at the end of the nineteenth century. Even in Great Britain its adoption proceeded rapidly in the 1880s, especially by the sales and improvement efforts of Ashworth Co.

The prevailing view towards the revolving flat card in India in those days was the following: the flat card was suitable only for the finer counts and the roller card was better adapted to the Indian mill, since the former was too delicate in setting for the average Indian worker. However, the applicability of this view was gradually disproved and the diffusion of the new machine began around 1890. According to the records of machinery ordered, which were from time to time available in the *Indian Textile Journal,* the revolving flat card was already strongly preferred by 1891 in cases of both new installations and replacement. Minor improvements and modifications in the carding engine continued to be made up to about 1910. Various makers were keenly competing with each

13 A great number of articles in the *Journal* were contributed by British textile experts. Most of the reproductions from foreign journals were adapted from British ones. It cannot, of course, be denied that the latter were in fact the most influential and broadly circulated in the world.

14 Partial information is available from the following sources: a short history of each mill in the *Indian Textile Journal* and *Centenary of the Textile Industry of India, 1854–1954* [4]; "suppliers of machinery and plants" for Bombay mills in S. M. Rutnagur, ed., *Bombay Industries: The Cotton Mills* [19]; the "technical section" in A. S. Pearse, *The Cotton Industry of India* [14], and so on. S. D. Mehta also gives an impressionistic quantification of equipment trends in his book *The Indian Cotton Textile Industry: An Economic Analysis* [11]. His appraisals of the diffusion of new machines seem to be too lenient.

other in the Indian market, but nevertheless the diffusion speed was not sufficiently high.[15]

In 1907 the first electric drive was installed in the Finlay Mill, Bombay, by a private power station.[16] This was a mere two years after the first electrification of a British cotton mill in 1905. Coincidentally, two Japanese cotton textile mills also initiated the first electric drives in 1907 by purchasing power from the public supply company, although the first drive powered by a private station was installed in 1903. It is estimated that in those days nearly 70 per cent of the total spindles in the United States were already electrically driven, and 45 per cent on the Continent of Europe. In contrast with these countries, the use of electric drive in Great Britain started very late and its diffusion speed was also slow.

At any rate, once the first electric drive was adopted in the British cotton textile industry, information on the new system of power transmission was immediately transmitted to India where it induced the heated discussions already referred to. Imports of induction motors and dynamos steadily increased after 1909, and this trend was markedly accelerated by the construction of the Tata Hydro-electric Power Station on the Bhore Ghats, Khandalla. By the end of the 1910s there existed at least twenty-one electrical undertakings in India, six using water power, five Diesel, and ten steam power. Electrification in the Indian cotton textile industry progressed at a reasonable pace, especially in Bombay City & Island where 80 per cent of all mills had been electrified by 1925,[17] although a number of mills in other textile centers were still mechanically driven by steam engines.

As for driving methods, the group drive was dominant in India for a long time. The British view on electric driving, as already mentioned, suggested that substantial benefits from the individual drive only existed for weaving sheds and Ring frames. This might be true, but we cannot exclude the possibility that the view was partly a justification for the prevailing use of group drives in old British Mule mills. Whatever the case, this theory was applied to the Indian cotton textile industry. It is, therefore, observed that the group drive was very popular, and only a limited number of mills had adopted the individual drive in their

[15] Most of the Japanese mills had adopted the revolving flat card from the beginning. This was partly owing to the privileged position accruing to latecomers. It was not until the year 1929 that the first domestically produced carding machine appeared. For the history of Japanese textile technology, the reader may refer to convenient references, such as S. Mori, *Bōseki* [Spinning] (Tokyo: Daiyamondosha, 1959); Nihon-sen'i-kyōgikai, ed., *Nihon sen'i sangyō-shi* [History of the Japanese textile industry], 2 Vols. (Tokyo: Sen'i-nenkan-kankōkai, 1958); R. Minami, *Dōryoku kakumei to gijutsu shimpo* [Power revolution and technical progress] (Tokyo: Tōyō-keizai-shimpōsha, 1976), and so on.

[16] Electric lighting for a cotton mill was first adopted in 1893, and gradually diffused thereafter. In the Japanese case, the corresponding date was 1886.

[17] This high rate was exclusively due to the existence of the Tata H.E.P.S. Co. Only four mills were self-supplied by private power stations. Almost all Japanese mills were electrically driven by the end of the 1910s. After 1915, large induction motors for group driving were supplied mainly by native makers in Japan.

weaving and Ring spinning sections by the end of the 1920s. These findings are also endorsed by A. Pearse's survey of 1930.[18]

The first automatic looms were employed by the Buckingham & Carnatic Mills, Madras, in 1914. However, their diffusion was very slow, even in the second half of the 1920s only two other cases being pointed out. Both these mills involved had adopted Toyoda automatic looms only on an experimental scale, ten to twelve looms being attended by one weaver. In the case of the over two thousand Northrop looms in the Buckingham & Carnatic Mills, one weaver attended only six looms. Based upon the performance of these applications, the Indian Tariff Board thus expressed its standpoint that power looms were preferable to automatic looms under Indian circumstances.[19] Whereas the economy of the automatic loom was gradually admitted, diffusion started only slowly in the 1930s.

In the previously mentioned survey of 1930 by A. Pearse, he revealed that several modern mills had already adopted the High Draft system, even in some cases for Mule spindles.[20] This was not particularly late by international standards, when we remember that in the British case the High Draft system had been applied to only half a million out of the 13.5 million Ring spindles installed in 1927. His survey also shows some of these representative mills adopting high speed winding and warping machines, the tape drive system, the Carrier type humidifier, etc. That is to say, we find here a symptom of the commencement of rationalization in the Indian cotton textile industry.

So far, the degree of diffusion for major textile innovations in India has been roughly sketched. The available information is admittedly insufficient, nevertheless a few features of technological transfers in India are discernible. First, while the initial adoption of new inventions was not necessarily very late by the standards of latecomers, the diffusion speeds were extremely low. This is in sharp contrast with the Japanese experience where, once an innovated system or machine was successfully introduced by some firm, diffusion proceeded quite rapidly, although the initial dates of adoption were not much different from the Indian ones. This fact implies that the Indian production market contained a good deal of heterogeneity, with mills ranging from progressive modern to conservative obsolescent and varying region by region.

18 A. S. Pearse [14]. In the Japanese cotton textile industry most mills had adopted the individual drive in the Ring spinning section by the mid-1920s. Weaving and carding sections were the slowest in adopting the individual drive. Full individual driving was diffused gradually in the 1930s.

19 *Report of the Indian Tariff Board* [8, p. 144]. Different cost estimates can be found in the *Indian Textile Journal* [9, Oct. 1931, p. 25]. The first adoption of an automatic loom in Great Britain was in 1902. Despite the establishment of British Northrop Co. in Blackburn, the diffusion there was slow. In Japan the first adoption in 1900 was a failure, but the new loom diffused very rapidly in the second half of the 1920s. At least twelve thousand of the native Toyoda automatic looms had been installed in the Japanese weaving industry by 1930, with one weaver usually attending thirty to fifty looms.

20 This system was originally developed for Ring frames, but was later applied to Mule spindles as well. Most Japanese mills introduced the High Draft system in the second half of the 1920s. Native machines of the Apron type were produced in Japan from 1931.

Secondly, dates of first adoption and diffusion speeds were both greatly affected by the British performance. This was chiefly owing to the twofold reason that the British cotton textile and textile machinery industries were, respectively, the dominant suppliers of information and machinery. Thirdly, the alleged incompetence of Indian workers was often used as an excuse to justify reluctance to introduce new technologies. While this might have been valid for some inventions, other inventions where the competence of workers was irrelevant were not easily introduced either. This suggests that the real problem of poor diffusion consisted not in workers' inabilities but in managerial deficiencies. To examine all of these aspects more systematically, we next discuss the problem of the diffusion of Ring frames, a problem of major significance and for which the necessary statistical data is available.

B. *Switching from Mules to Ring Frames*

1. *The growing advantages of Ring frames*

As is well known, the first Ring frames in India were introduced by J. N. Tata's Empress Mill in Nagpur. They were installed after cautious experiments by a textile expert, Brooksby, who had brought back the frames from Great Britain on his return from leave in 1883. These Ring frames were two short (sixty-four spindles) frames of the Rabbeth type made by Brooks & Doxey Co. Brooksby and his colleague, R. Roscoe, succeeded in producing seven ounces per day of 26's yarn from Indian cotton after a long struggle to invent an anti-balloon apparatus (a primitive separator). Immediately after the success, the first four long Ring frames were ordered and gradually replaced Throstle and Mule spindles in the mill.

The Ring spindle itself underwent a long gestation period before being adopted for practical use. During the 1830s and 1840s various types of Ring spindles were studied and efforts were made to overcome their defects by many inventors and machinists in the United States. But most of the attention was centered on a British innovation, the self-acting Mule invented by R. Roberts in 1830. Thus it was not until the 1870s that great progress was registered in Ring spindles, especially through the efforts of two Americans, J. Sawyer and F. Rabbeth, and their productivity surpassed that of the Mule for coarse yarn production. The so-called Sawyer and Rabbeth spindles were patented in 1871 and 1878, respectively. They were the prototype of present Ring frames, the first to overcome the lubrication difficulty, and were a self-contained spindle with bolster bearings within a bobbin. The efficiency was steadily increased by subsequent variations, appearing as the "gravity," "elastic," "flexible" spindles, and so on.

In the first half of the 1890s the Mule and Ring advocates proclaimed the respective advantages of their choice in the *Indian Textile Journal*. The Mule advocates maintained (1) that the yarn produced by Mule spindles was more uniform, softer, and more elastic than that produced by Rings, and hence it was more appropriate for the weft, and (2) that the initial investment could be much smaller, since the price per spindle was about 5s. 6d. for Mules as opposed to 8s. for Rings. They also claimed (3) that the Mule spindle could spin from the lowest to the highest counts, and (4) that to change counts on the Mule was much easier and cheaper than on the Ring, the Mule not requiring any costly stock of bobbins.

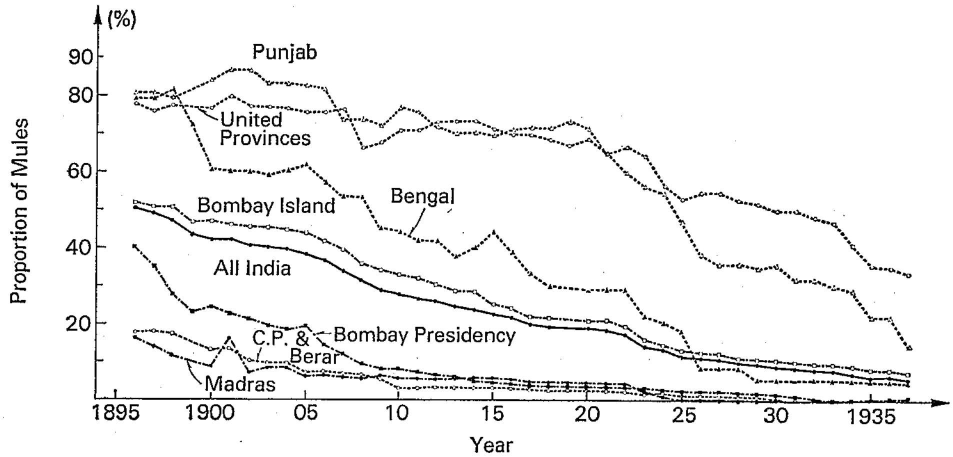
On the other hand the Ring advocates pointed out (1) that the Ring frame could give greater productivity in stronger yarns up to 40's. In the case of weft 20's, the Ring and Mule should respectively produce 7.5–9.0 ounces and 6.0–6.5 ounces per spindle per day (12.5 hours). That is to say, the former could produce 15–50 per cent more. Besides, the price of the Ring yarn was said to be slightly higher than that of the Mule,[21] since stronger yarns were preferred in the Chinese market. (2) The structure of Ring machines was much simpler, and this yielded various benefits. For instance, the Ring frame could be much more easily attended by fewer workers. This advantage was especially emphasized in Japan on the grounds that even unskilled female workers and children could easily look after it. The simplicity also implied smaller wear and tear of the machine which therefore required fewer replacement parts and less complicated repairs. The running cost of the Ring was thus estimated to be cheaper by 10–20 per cent. (3) Some other advantages were proclaimed by Ring advocates as well: smaller floor space (two-thirds of the Mule's), fewer spindle stoppages at a time, less cop bottom waste, lower power consumption per unit of output (not per spindle), etc.

In short, apart from the second lower initial cost, the advantages of the Mule are judged not to be particularly significant especially to the Indian cotton textile industry as a coarse yarn producer, when we bear in mind the various advantages of the Ring. On the other hand, the second advantage must have been crucial to managing agencies and directors who were almost always facing financial difficulties. Had the directors, however, had a long-run view of management in adopting new machines, the superiority of the Ring over the Mule should have been obvious at the latest in the 1890s, since the greater production and smaller running cost of the former could easily offset the greater initial investment within several years under normal market conditions. In other words, the reason why Mule spindles continued to be imported even after the 1890s has to be solved with reference to other considerations than simply the productivity of the machines.

In Great Britain, the first Ring frames were introduced by Bright Bros. Ltd. of Rochdale in 1874. Their diffusion was, however, very slow and involved an almost desperate contest with British conservatism or the disinclination of manufacturers to make drastic changes. Around 1920, 80 per cent of all spindles were still Mules, notwithstanding the fact that more than 70 per cent of the yarn produced by the British cotton textile industry was under 40's. By contrast, textile industries in the rest of the world had already replaced 80 per cent of all spindles with Ring frames by that time. In Japan the Mule was surpassed

21 Weft 20's Ring yarn was said to be about a quarter anna more expensive at that time. See, for instance, the *Indian Textile Journal* [9, Sept. 1893, p. 240] which mentions also the price of the machines.

Fig. 2. Proportion of Mules in Total Spindles by Regions



Source: *Report of the Bombay Millowners' Association* [16], respective years.
Notes: 1. Some figures are lacking for the years 1899 and 1919.
2. Throstles are not distinguished from Rings for the earlier period.

by the Ring in 1889, and soon the latter accounted for 80 per cent of all spindles (1893) due to successive entries with new installations. This rapid switch was partially due to the fact that the industry was still small as a latecomer.

In the year following the first Ring installation in India by the Empress Mill, a complete Ring mill was established using Rabbeth spindles supplied by Howard & Bullough Co. and its Bombay agent, Greaves, Cotton & Co. This was the Connaught Mill, which acted as the fuse of a Ring frame construction boom lasting to around 1895. By 1891, 938,000 Ring spindles were already installed, accounting for 28 per cent of the total 3.3 million spindles. As shown in Figure 2, half of all spindles were Ring frames by as early as 1896. This may be considered a rather rapid diffusion when we take into account the size of the industry at that time. Thus the period from 1885 to 1900 is characterized by the relatively high speed of diffusion which is commonly observable at the initial stage of any diffusion. However the diffusion rate in the subsequent stages declined sharply (cf. Figure 2), giving rise to the more serious problems remaining to be examined in a broader perspective.

2. *Implications from a regression analysis*

The decision on whether to introduce some important innovation commonly belongs to all members of the board of directors. In cases where directors do not have sufficient knowledge to judge, the decision is frequently shared with middle management staff, namely, managers, carding, spinning, and weaving masters, or engineers. As previously pointed out, foreign textile experts in top or middle management played a crucial role in such cases in the Indian cotton textile industry.[22] Hence we should like to analyze the factors determining the diffusion rate of Ring frames from the viewpoint of roles taken by managerial staff, specifically by foreign staff in top and middle management. For this purpose a regression analysis is first applied to the regionally aggregated data in order to grasp the problem quantitatively.

The statistical data used here cover (i) six areas, viz., Bombay Presidency, Madras Presidency, Bengal Presidency, Central Province & Berar, the United Provinces of Agra & Oudh, and Punjab, and (ii) the time-span from 1897 to 1937 (five-year intervals). These cross-sectional and time-series data are pooled in the regression analysis to increase the sample size. The proportion of Mule spindles to total spindles (y; cf. Figure 2) is considered to be explained by the following five variables: the increase in Ring spindles for the previous five years deflated by the number of mills in each region (x_1); the number of students in technical education institutions deflated by their relative size of population in the 1911 census (x_2); the proportion of foreign directors to all directors (x_3); the proportion of foreign staff to all middle management staff (x_4); and the time trend (x_5).

The expected signs for these variables are a minus for x_1, x_2, and x_5, and a plus for x_3 and x_4. The increase in Rings as a flow variable and the time elapsing indicate the results of technological choices and physical obsolescence,[23] which reduce the Mule ratio. Also, the progress of technical education may increase the tendency for decision-makers to make rational technological choices by spreading the relevant knowledge, in other words, promoting the adoption of Ring frames in the long run. On the other hand, higher proportions of foreign staff in top or middle management are interpreted as a stronger influence on the selection of new machines, specifically through the greater likelihood of recommendations to adopt the Mule spindles with which they were more familiar in the home country.[24]

The data for y and x_1 are adapted from *Report of the Bombay Millowners' Association* [16], for x_2 from *Progress of Education in India* [15], and for x_3 and x_4 from *Thacker's Indian Directory* [22] and *Indian and Japanese Textile and Engineering Diary* [7] of respective years. In the case of the latter two, numbers of foreigners are assessed on the basis of judgments from names.[25] The figures

22 Japan's history shows that her dependence on foreign technicians and experts was, in a comparative sense, very small from the beginning of her industrialization. Their stays in the country were in most cases limited to from one to three years. This was particularly true for the cotton textile industry.

23 It should be noted that textile machinery in India was ordinarily operated beyond its formal working life span, commonly for thirty-five to fifty years. Machines were often replaced just prior to the scrapping limit.

24 A. S. Pearse may share our view, since he expresses the impression that "the effect of the presence of a large number of Lancashire inside managers is reflected by the relatively high proportion of mules to ring" [14, p. 153].

25 Most of the foreigners were British, although some continental Europeans were identified as well. Jews are also classified as foreigners according to their names, notwithstanding the fact that some such classifications are probably inappropriate. Typical pseudo-British

are aggregated for each of the six regions. In the case of 1897 alone, the foreign director ratio is substituted as a proxy by the proportion of de facto foreign managing agencies to all managing agencies, since the available sample on the former is too small for the year, and as a rule the two ratios are highly correlated with each other.

As we should like to grasp the contribution of each variable in explaining the level of the Mule ratio, the standardized version of a regression equation is first calculated as Equation (1),

$$\underset{(-2.40)}{y=-0.260x_1}+\underset{(2.97)}{0.450x_2}+\underset{(2.14)}{0.326x_3}+\underset{(0.76)}{0.133x_4}-\underset{(-4.00)}{0.594x_5}, \quad (1)$$

$R^{*2}=0.393$, the figures in parentheses being the t-values.

This shows that the variables on obsolescence replacement (x_5), foreign directors (x_3), and Ring investment (x_1) may explain, to some extent, the decreasing trend of the Mule ratio, but that the variables on technical education (x_2) and foreign middle management staff (x_4) betray our expectations with the reverse sign and an unreliable coefficient, respectively.

The poor fit of Equation (1) might be due to its common constant term, since Figure 2 suggests the existence of different constant terms for different regions. Hence we next introduce dummy variables D_1 to D_5, corresponding to the respective constant term for each of the above regions. The estimated result of the non-standardized version with regional dummies is,

$$y=\underset{(9.59)}{1.000}-\underset{(-0.43)}{0.002x_1}-\underset{(-1.90)}{0.052x_2}-\underset{(-0.36)}{0.054x_3}-\underset{(-1.25)}{0.164x_4}-\underset{(-4.03)}{0.009x_5}$$

$$-\underset{(-7.44)}{0.399D_1}-\underset{(-6.90)}{0.567D_2}-\underset{(-3.05)}{0.281D_3}-\underset{(-7.38)}{0.677D_4}+\underset{(0.26)}{0.032D_5}, \quad (2)$$

$R^{*2}=0.886$.

As expected, the coefficient of determination has greatly increased as the result of better fit stemming from the separate constant terms, whereas only the coefficients of independent variables x_5 and x_2 are reliable, judging from their t-values.

Thus, taking these two results in combination, it seems advisable to draw the modest conclusion that the only key factor in explaining the changes in Mule ratios is nothing but the direct variable of replacement, as long as our analysis is based upon regionally aggregated data. This result is perfectly consistent with our previous analysis, where the depreciation policy was said to be quite poor mainly due to the myopic behavior of directors and managing agencies.[26] That

names of Parsis are regarded as Indian unless their full names are available. Such names include Cooper, Carpenter, Driver, Fitter, Engineer, Major, Marshall, Master, Secretary, etc.

26 See Y. Kiyokawa, "Indo menkōgyō ni okeru gijutsu to shijō no keisei ni tsuite" [Technology and market formation in the Indian cotton textile industry] [10]. It may be useful for us to be reminded of the appraisal therein that the Ring's diffusion in India was relatively slow, considering that her industry was producing predominantly coarse yarn.

is to say that the slow diffusion of Ring spindles, except in the initial stage, was chiefly determined by the poor replacement policy for old spinning machines. Insofar as the macro analysis of diffusion is concerned, the roles of foreign staff and the effect of technical education were not directly extractable, as those variables had not the robustness of specification. However, despite this, the problems are not entirely solved, since we still have to explain why Mule spindles continued to be imported and why regional differences existed in the diffusion of Rings.

3. *Regional differences and irrational choice of technique*

Figure 2 shows the large variation in Mule ratios (or, conversely, the diffusion rates for Ring spindles) for different regions not to be reduced up to around 1920. Hence it must first be asked whether such great diversity is simply a reflection of variations in the starting dates of rapid development of the industry in different regions. In other words, the wide variation in Mule ratios may be explained by whether or not the Ring spindle was available when the initial development began in a region. This distinction between the initial and replacement investment in Ring frames could explain the different rates of Bombay City & Island and other areas of Bombay Presidency. Since most of the mills in Bombay City & Island were established before 1900, especially in the 1870s and 80s, and in Ahmedabad and other areas, the development occurred after the 1880s and particularly after 1893. The high proportion of Mules in Bengal Presidency might also be explained by its earlier development, yet for other regions, such as the United Provinces or Punjab, the explanation must be sought elsewhere.

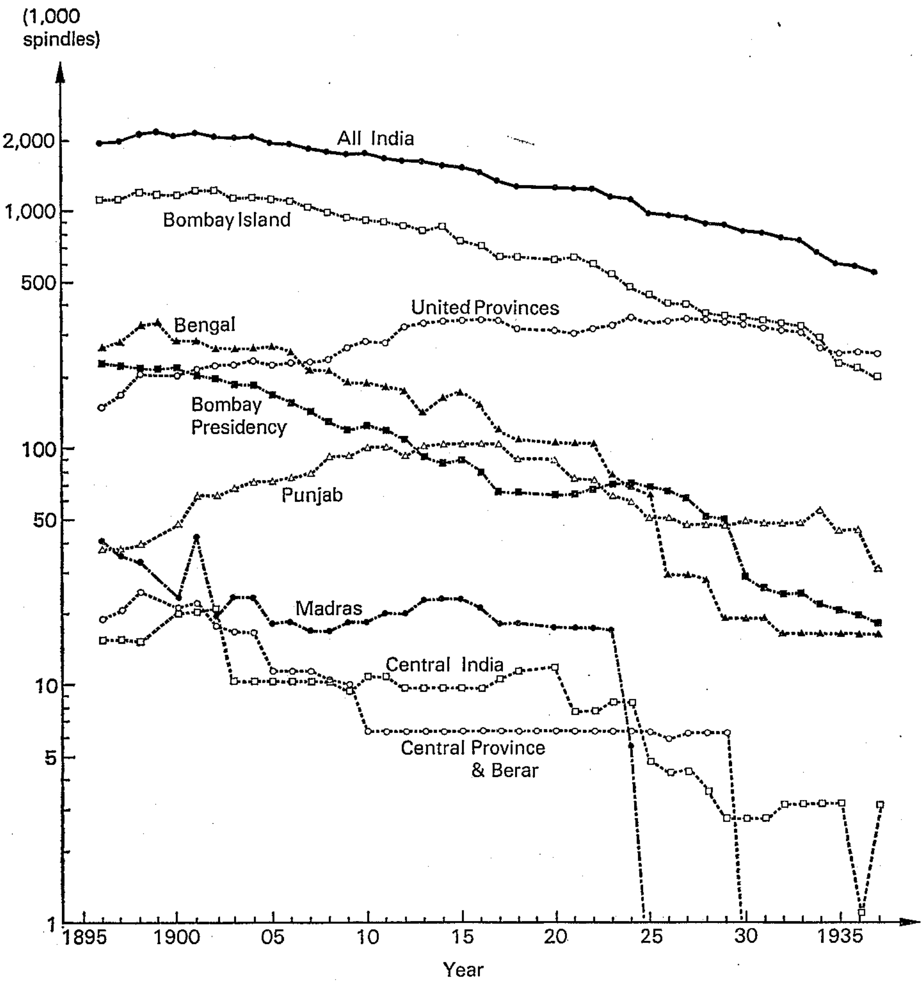
It is true that the slow diffusion of Ring frames after 1900 was basically due to the stagnation of the industry itself. The poor replacement policy was a result of the stagnation, but at the same time it was a cause of it as well, since the poor depreciation policy was nothing but the expression of the conservative attitude towards technological progress. An example of such conservative behavior towards the introduction of an innovation is equally to be found when the replacement of Mules by Ring frames is more closely examined.

Changes in the absolute number of Mule spindles are given in Figure 3, which suggests that more than 2 million Mule spindles were operated and maintained for twenty years up to the beginning of this century.[27] It is to be noted that our data show net figures of the stock, i.e., the installed number of spindles. Hence Figure 3 implies that not a small number of Mule spindles must have been imported to replace other Mule spindles even after the first introduction of Rings in 1885.[28] As typically confirmed in the United Provinces and Punjab, the

27 More than 2 million spindles were already installed in 1884. The figure might include some Throstles, but Rings did not yet exist.

28 This possibility was also pointed out by Dr. G. Saxonhouse in a private discussion based upon his research. Although the gross flow data do not exist, partial information for newly constructed mills is available from *Report of the Bombay Millowners' Association* [16]. It proves that Mule spindles were being adopted in new mills even in the mid-1920s.

Fig. 3. Absolute Numbers of Mule Spindles Installed



Source: The same as for Figure 2.
Note: The figures for Madras in 1901 and Central India in 1935 seem to be erroneous, but have not been corrected.

number of Mule spindles continued to increase up to the mid-1910s. These facts suggest that some reason other than slow replacement must have been the real cause for the slow diffusion of Ring spindles, since adherence to the old-type Mules continued for such a long time.

The proportion of Mule spindles imported after the 1890s might be a mere fraction of the total number of spindles, nevertheless it appears to harbor some serious implications for understanding the problem of technological choice in India. It is obvious from what we have discussed above that to select the Mule spindle after the 1880s was not rational for the cotton textile industry in India, particularly in the United Provinces and Punjab, since the two regions were typical coarse yarn producing areas. For instance, in the mid-1890s 80 and 95 per cent respectively of the yarns produced in these regions were 11's–20's,[29] and even in the mid-1910s the proportions were 70 and 85 per cent, much higher than the national average (65 and 55 per cent for the same periods).

Nonetheless, in both regions more than 70 per cent of the spindles employed were Mules, up to around 1920. It appears almost irrational for coarse yarn producing areas to maintain such high Mule ratios. The only justification might be financial difficulties, as the price of Mules was lower than that of Rings in the 1890s (though not necessarily after the 1910s). But financial difficulties were not a characteristic peculiar to those regions but, rather, a general feature common to all Indian mills. Thus all we can do is to admit the existence of great regional differences among the various textile centers.

Each center showed its own developmental pattern. One center developed through a sharp increase in the number of mills with the size remaining constant (e.g., Ahmedabad). Another center developed through an increase in mill-size with the number of mills remaining fixed (e.g., Central Province). A third type realized its development through increases in both mill-size and mill-number (e.g., Madras). It is difficult, however, to find any relationship between the Mule ratios and these divergent developmental patterns among different regions. All we can see is the sharp contrast between the similarity of adaptation patterns within a region and the great variations between regions. In other words the production market for cotton yarns and fabrics was distinctly divided up, and the flow of technological information was quite limited between regions.[30] We are thus brought back again to the problem of information routes for individual mills and must analyze the problems through reference to the micro data.

III. FOREIGN TECHNICIANS AND INDIAN DIRECTORS IN THE PROCESS OF TECHNOLOGICAL CHOICE

A. *The Significance of Foreign Technicians and Progress in Technical Education*

1. *The high dependence on foreign staff*

The close relationship of the Indian cotton textile mills with foreign experts was firmly established in the industry from its initial stage. Native investors or mill-promoters such as cotton merchants, indigenous bankers, etc., had no knowledge at all about the factory system or the mechanics of textile machinery. Assistance from British machinery makers, fitters, or techno-managerial staff was

29 It is usually said that for waste spinning the Mule spindle is more appropriate than the Ring frame. But this is not applicable in these cases, since the proportion of yarns under 10's was small for both areas.

30 It was frequently observed that one type of machine was popular in one center, and another type in another center without any clearly discernible cause. Strange enough, machinery productivities also differed greatly among different centers. Fragmental information on such phenomena is obtainable from the *Indian Textile Journal*. As for the fragmented markets in India, see, for example, Y. Kiyokawa [10].

indispensable to promoters many of whom had no higher education. Most owners or directors, lacking in the consciousness of the industrial capitalist, did not show any strong interest in mill management. Thus the actual trades involved, as well as the management of the mills were commonly subcontracted and executed by so-called managing agencies which were organized by small groups of merchants, bankers, accountants, or lawyers, but rarely engineers.

As these agencies did not ordinarily contain mechanical experts, mills were frequently erected and started operations under the initiatives of machinery makers. Furthermore, makers often had to send mill managers and departmental masters from Great Britain to maintain the subsequent operation and management. In fact, this was a common phenomenon when new mills were constructed in the earlier stages of the development of the Indian cotton textile industry, and thus the number of foreign experts increased along with the development of the industry, from the first arrival of a Lancashire man, P. Rushkin, in 1854, until, by the end of the 1880s, at least one hundred European experts (mostly British) had joined the industry. On the other hand, many natives, especially Parsis, were technically trained as assistant masters under the guidance of European technicians, although their knowledge did not extend to scientific understanding but involved merely rules of thumb acquired through apprenticeship.

Some of these Europeans and Parsis joined newly constructed mills as directors or members of the managing agencies, but such situations only occurred during the earlier development of the industry. In practice, almost all technicians from European countries worked as middle management staff, i.e., as mill managers, departmental masters, or engineers. Such technical cadres are said to have enjoyed greater freedom and less responsibility than in their home countries, but had to suffer the incompetence of the top management and the supervisory class. When we compare this picture with the Japanese experience, the heavy dependence on foreign staff appears to be just synonymous with defective top management, since most top management staff never even tried to make an effort to understand textile technology.

It is noteworthy that even among European directors only a few were technically trained or possessed sufficient knowledge of the mechanics and working of cotton textile machinery.[31] Most were traders or brokers, although they did

[31] Some information on European directors in Bombay City:

	1913 [59]				1925 [81]			
	Agency Director	Outside Director	Total	Technically Trained	Agency Director	Outside Director	Total	Technically Trained
European directors	(6) 16	14	30	4	(5) 13	11	24	2
Indian directors	(32) 65	67	132	8	(36) 82	69	151	9
Total	(38) 81	81	162	12	(41) 95	80	175	11

Sources: *Indian Textile Journal,* August 1913, and *Bombay Industries: The Cotton Mills* [19, pp. 249–80].
Notes: Figures in [ ] denote the total number of mills covered by the data. Figures in ( ) denote the number of managing agencies.

TABLE I
PROPORTIONS OF FOREIGN STAFF IN MIDDLE MANAGEMENT

	1897	1902	1907	1912	1917	1922	1927	1932	1937
By occupation:									
Manager	0.5789	0.4928	0.4503	0.3810	0.4179	0.4174	0.3525	0.1641	0.1804
Carding master	0.3387	0.4175	0.4070	0.3613	0.3737	0.3474	0.3096	0.2025	0.1913
Spinning master	0.3846	0.4369	0.4639	0.3583	0.3713	0.3257	0.2835	0.2460	0.1945
Weaving master	0.2963	0.3148	0.3824	0.3019	0.3400	0.3187	0.2710	0.2269	0.1624
Engineer	0.4947	0.4198	0.3316	0.2796	0.2233	0.2284	0.1767	0.1368	0.1000
By region:									
Bombay C. & I.	0.3696	0.3276	0.3427	0.3861	0.3653	0.3798	0.3183	0.2373	0.2153
Bombay others	0.3529	0.3750	0.2859	0.2129	0.2110	0.1644	0.1415	0.1491	0.1267
Madras P.	0.5769	0.7442	0.7429	0.5532	0.6250	0.7115	0.3977	0.3333	0.1029
Bengal P.	0.6429	0.6250	0.5593	0.4773	0.5357	0.5200	0.4730	0.2063	0.1384
C.P. & Berar	0.3684	0.2903	0.2632	0.2821	0.3056	0.3947	0.1818	0.1525	0.1231
United Provs.	0.8333	0.8571	0.8108	0.6739	0.7069	0.5075	0.5851	0.4471	0.3618
Punjab	1.0000	0.4211	0.2381	0.1786	0.2143	0.1667	0.1887	0.1111	0.1429
(All British India)									
No. of posts occupied by foreigners	162	228	214	312	327	347	352	267	244
Total no. of posts[a]	350	529	521	918	949	1,063	1,268	1,301	1,479
Average proportion	0.4629	0.4310	0.4107	0.3399	0.3446	0.3264	0.2776	0.2052	0.1650

Sources: For 1897–1907, *Thacker's Indian Directory* [22] for respective years. For 1912–37, *Indian and Japanese Textile and Engineering Diary* [7], 1913, 1918, 1923, 1928, 1933, and 1938, respectively.
[a] Posts for which names are not available are excluded.

have close contact with textile machinery makers. About half of them were so-called agency directors. In any case, the proportion of European directors was not very high, and their influence and role in the industry are not considered to have been crucial except in some special centers such as Kanpur and Calcutta. Rather, their market behavior was quite similar to that of native directors. Consequently a large degree of discretion in matters of technological choice and machine operation was left to the middle management staff, specifically the European technical cadres.

A large number of technical experts were in fact sent to India by machinery makers. After the mid-1870s, many makers established showrooms and agents in Bombay and eagerly tried to make use of such experts as a means to cultivate the market. In 1890, nearly 60 per cent of the technical posts in middle management in the industry were occupied by foreign technicians. As shown in Table I, the proportion gradually decreased to 17 per cent in 1937 through replacement by Indian staff. The reasons were twofold: First, technical education in textile expertise started in 1887 was steadily developed, especially after the mid-1920s. The effect can be observed in the 1930s as a sharp decline, not only in the proportion, but also in the absolute number of foreign staff. Secondly, to obtain qualified foreign technicians became more difficult year by year as the industry expanded. Table I implies that the net increase in the number of foreigners must have been small from 1912 to 1927, considering the increase in multiple office-holding.

Regional differences in foreign technician ratios are distinctly discernible up to around 1920, although the variation was relatively smaller in the earlier period.[32] For purposes of the later discussion it may be noted here that the ratios in the United Provinces, Bengal and Madras presidencies were relatively high, whereas Punjab had the lowest ratio after 1907. Occupational variation was in general smaller than regional variation. Again, foreigners were more equally distributed in the earlier stages, but the replacement speed differed for different occupations. Foreign engineers were the earliest to be replaced by Indians, whereas the post of manager witnessed the slowest substitution. These patterns were essentially common to all regions.

However, the substitution of foreign technicians by Indian graduates did not necessarily progress smoothly. The top management frequently complained about young Indian graduates' qualifications, e.g., their disinclination towards apprenticeship and their lack of practical knowledge. These complaints occasionally led to criticism of technical education itself. On the other hand, there were also complaints about European technicians, since not a few of them were also insufficiently qualified for their offices despite the high salaries. Their qualifications will be examined next.

2. *The quality of foreign staff and their lives*

It is well known that most European technicians came to India through the good offices of textile machinery makers, although some of them were recruited by advertisements in the newspapers or directly by the Manchester agents of Indian millowners. Many of them were said to have been fitters or engineers in their own shops, and not real managers or masters of cotton textile mills. This situation could arise partly because of the difficulty experienced by makers in finding capable technical cadres in Great Britain, and partly for the very reason that the fitter was a kind of agent for the machinery maker. Quite often, the fitters sent out by the machinery makers to install new machines for Indian mills were placed in charge of the managers or masters when the textile machines began working.

As neither managing agencies nor boards of directors understood even the most basic principles of textile technology, serious problems associated with the fitter-manager or the fitter-master were realized only after their employment. Neither all of the European techno-managerial staff were fitters or engineers, nor were all fitters incompetent. But the defects of fitters as managerial staff are obvious in our context. First, they were said to have insufficient knowledge of the principles of manipulation of the cotton fiber and of the work performed

[32] In 1890, the ratios were as follows: Bombay C. & I., 54 per cent; Bombay others, 66 per cent; Madras, 69 per cent; Bengal, 67 per cent; C.P. & Berar, 63 per cent; the United Provinces, 68 per cent; Punjab, 67 per cent; and all India, 59 per cent. By occupations, the ratios were: manager, 61 per cent; carding master, 59 per cent; spinning master, 62 per cent; weaving master, 40 per cent; and engineer, 64 per cent. These are obtained from the same source: *Indian Textile Diary,* ed. W. H. Gribbin (Bombay, 1891) (later, *Indian and Japanese Textile and Engineering Diary*).

by different machines, although they understood the mechanisms of the textile machinery itself. Most fitters in Great Britain hardly had any formal middle education in science or engineering, as they ordinarily started an apprenticeship in a machine shop from around fifteen years of age. Thus it is not surprising that the quite limited knowledge held by a fitter was not up to the demands of the whole production system of either a mill or a department, the understanding of which was essential to the management.

Secondly, it is said that fitters occasionally earned double commissions from an Indian mill on the one hand and a machinery maker in the home country on the other by persuading the top management of a mill to adopt some particular brand of machines. The fitter's preference was usually based upon personal connections and his former experience acquired in Great Britain. As a result, the most up-to-date machines were seldom adopted. These two defects of the fitter as managerial staff might be considered the extreme cases. But to some extent similar problems were also attached to *bona fide* British managers and masters in India, because of their technical background in Great Britain and their strong connections with machinery makers.

On the other hand, it was certainly true that the Indian cotton textile industry failed to offer sufficient incentives to attract competent managers or masters. Indeed, it was almost impossible to do so. In the 1890s the salaries of a manager and a carding or spinning master were said to be Rps.450–600 and Rps.200–400, respectively, with free quarters and medical attention. Such remuneration is regarded as being 2 to 3 times that for Indian staff and was in fact almost equal to or even slightly better than the salaries for managers or masters in Great Britain,[33] although it was often misunderstood by Indian managements as being much higher. In other words, such amounts were not at all sufficient to induce genuine managers and masters to come to India, when they considered the various kinds of risks attached to working in the Indian cotton textile industry.[34] The fact that most respondents to recruitment advertisements by Indian

[33] For instance, Rps. 450 per month, was in those days equivalent to around £30, i.e., £6–7 per week. This was within the range of managers' average salary of £5–8 per week in Great Britain, whereas masters' and fitters' salaries were £1–3 and £1.0–2.10 respectively. In the mid-1880s, the salaries for managers and masters were Rps. 350–450 and Rps. 250–300 respectively. In the mid-1920s they were Rps. 1,500–2,000 and around Rps. 800 respectively. See the *Indian Textile Journal* [9, June 1892, p. 181] [9, Apr. 1928, pp. 226–27]. An allowance for fuel and servant, an annual increase of Rps. 50 a month, full passage out and home, and six months leave every four (or five) years on full (or half) pay were also assured in most cases. The total expense to a mill was, hence, much more than 2 to 3 times that for a native, even though this disposable income was not sufficient to attract managerial applicants.

[34] Their life in India was rather hard in both the mental and physical senses. There was also some anxiety about life after their return. Most of insurance companies regarded India as a most dangerous place for Europeans, and charged 50 per cent excess premium for those resident there. Cf. the *Indian Textile Journal* [9, Mar. 1895, p. 130]. Information on foreign staff in the earlier period is available in S. D. Mehta, *The Cotton Mills of India, 1854 to 1954* [12].

managing agencies in the *Manchester Guardian* were not *bona fide* managers or masters proves the above conjecture.

There was yet another important factor allowing for the strange phenomenon, namely, the existence of the fitter-manager or engineer-manager in the Indian industry. Managing agencies are said to have always tried to save the salary of a foreign manager. That is to say that the top management itself showed a readiness to accept such cheaper managers without regard to their qualifications. Even in cases where machinery makers had explicitly advised them that fitters or engineers were unable to fully understand the whole system of spinning and weaving lines, they were said to prefer the cheaper managers and masters. This was a function of their utter ignorance of the significance of techno-managerial staff. Consequently the Indian cotton textile industry employed not a few unqualified foreign managerial staff, and the ultimate responsibility for this should be attributed to the Indian top management.

Foreign technicians were gradually replaced by Indian managers and masters, as was shown in Table I. But the industry again had to suffer from similar problems in the substitution process, because some of the Indian technicians had an even narrower knowledge of the practice of machine operation and maintenance. While others, it was said, curried their directors' favor by increasing production through extremely high speed operation, which necessarily led to machine breakdowns and poor quality output. Furthermore, employment contracts for middle management were very short in India, viz., two to four years for both foreign and native technicians. Hence, their rates of turnover were in general incredibly high, partly owing to the mutual distrust between them and the managing agencies. In short, although there were various factors at play, the final responsibility for the high dependence on foreign staff for such a long time, we would like to claim, must be assigned to the incompetence of the top management in the Indian cotton textile industry.

3. *Technical education of textile experts*

The costs and benefits of employing foreign technicians were first extensively discussed in the *Indian Textile Journal* in the mid-1890s. This was a symptom of the birth of a new native technical cadre class. It cannot be denied that the replacement of foreign staff by Indians progressed in parallel with the development of technical education, even though Indian technicians were attended by a lot of problems. The Japanese experience reminds us that the rapid progress of technical education may be regarded as one of the necessary (but not sufficient) conditions for the rapid development of industries in a late-coming country. Judged in this light, the progress of technical education in India was not necessarily speedy enough.[35]

[35] Indians had already noticed that Japanese technical education was far more advanced than their own as early as the beginning of the twentieth century. Indian students were sent to Japan for study from 1904. Japan's educational system was also studied by the Bureau of Education which compiled *The Educational System of Japan* [21] in 1906.

The basis for higher education was established in the 1850s when the universities of Calcutta, Madras, and Bombay were started as an affiliate college system. All of these universities can be characterized as heavily liberal-arts-oriented institutions, in contrast with the two colleges of engineering at Rurki and Pune which were already open and operating on a small scale as early as 1847 and 1854 respectively. Yet graduates from the engineering colleges, like those from the universities, were exclusively employed by the government, especially the Public Works Departments of the various provincial governments. That is to say, it can be maintained that the main purpose of higher education, including science and engineering, was to produce human resources for government administration, not to provide highly educated personnel for the industrial world. In other words, industries still had to seek competent staff from the lower level educational institutions.

It was in the 1880s that Indian society, both the private sector and the government, came to seriously feel the necessity of technical education and the hitherto overemphasis on literary education. In 1887 the first real institution for technical education, the Victoria Jubilee Technical Institute, Bombay, was established to promote industrial progress, constructed mainly by private efforts with the aid of various funds. About a decade and a half later, the Simla Educational Conference was held in 1901 to reflect Viceroy Curzon's intention of expanding technical and industrial schools, yet the response by local governments to his idea was pathetic, and led the central government to conclude that there was not much genuine demand for technical education. On the other hand, the Indian National Congress had, since the 1880s, repeatedly demanded the expenditure of more money and effort on technical education, particularly at the beginning of the twentieth century when it was backed up by the Swadeshi movement.

It is noteworthy that there existed two important controversies on technical education from the outset, the first concerning its effectiveness and the second the real demand for it. The *Times of India* and the *Indian Textile Journal* often devoted space to controversies of the first problem. And the main purpose of the Atkinson-Dawson Committee in 1912 was to survey this very problem from the viewpoint of apprenticeship.[36] On the other hand, the second problem occasionally surfaced as a confrontation between British specialists and Indian educationalists, as shown by the example of the separate note by M. Malaviya in the Report of the Indian Industrial Commission of 1918. Another, perhaps more typical, example was the reports of the Vishweshwaraya Committee submitted to the government of Bombay in 1922, when the committee in fact submitted two reports, a majority report by its European members and a minority report by its Indian members, the former being said to concern the excess supply of the technically educated.[37]

Despite the existence of these problems, Indian technical education started to

[36] See E. H. V. Atkinson and T. S. Dawson, *Report on the Enquiry to Bring Technical Institutions into Closer Touch and More Practical Relations with the Employers of Labor in India* [2].

[37] The reports were shelved and never again saw the light of day.

TABLE II
GROWTH OF INSTITUTIONS FOR TECHNICAL EDUCATION

	Bombay Presidency		Madras Presidency		Bengal Presidency[a]		Central Province & Berar	
	No. of Inst.	No. of Stud.	No. of Inst.	No. of Stud.	No. of Inst.	No. of Stud.	No. of Inst.	No. of Stud.
1897	16	1,223	4	137	23	623	3	47
1902	19	1,829	12	406	26	756	6	204
1907	31	2,063	14	290	52	1,275	5	136
1912	31	2,667	44	2,121	87	2,028	7	289
1917	26	1,798	41	2,078	97	3,351	9	350
1922	31	1,829	41	2,039	118	5,174	7	298
1927	33	2,878	64	4,343	196	8,696	2	101
1932	44	2,895	74	5,769	192	8,394	2	149
1937	64	3,858	86	7,521	202	9,557	13	794

	United Provinces		Punjab[b]		All British India	
	No. of Inst.	No. of Stud.	No. of Inst.	No. of Stud.	No. of Inst.	No. of Stud.
1897	2	296	7	759	57	3,101
1902	9	736	7	962	84	4,977
1907	11	782	19	1,639	147	6,820
1912	35	1,671	30	2,614	242	12,064
1917	28	1,478	35	3,230	251	12,706
1922	37	1,780	26	2,572	276	14,082
1927	111	3,941	25	3,798	450	24,537
1932	107	3,933	45	4,852	483	26,711
1937	95	3,833	58	4,229	536	30,548

Source: *Progress of Education in India* [15], quinquennial reports (3rd–11th).
[a] Bihar and Orissa are included.
[b] Delhi is included.

develop at a reasonable pace from the 1920s. The increase in numbers of institutions and students enrolled is given in Table II. There are two things which should be particularly noted from the table: First, even when compared with the Japanese experience, the overall size of Indian technical education was not especially small after the mid-1920s, although it may have been too small in the earlier period relative to the scale of the manufacturing industries. Hence, if any problems did exist, they must be sought in other aspects such as the quality of students, teaching staff and facilities, the footing of general education, etc. But the figures of Table II contain technical education institutions of various qualities. Secondly, regional differences in the progress of technical education are clearly observable, especially when we take into account the population size of the respective regions.[38] In this perspective, Punjab and Bombay Presidency were

[38] The proportions of population in each region based upon 1921 census are Bombay, 0.089; Madras, 0.186; Bengal, 0.36; Central Province and Berar, 0.063; the United Provinces, 0.212; and Punjab, 0.090.

relatively advanced, while Central Province and the United Provinces were backward regions.

It may be worthwhile to mention some other characteristics as well. The educational system in India was basically an imitation of the British. In the field of technical education, however, the night school and the sandwich system were rarely adopted in India. As for the personal backgrounds of students, only one-third of all students studying in technical and industrial schools came from rural areas, whereas two-thirds of all students receiving vocational education were of rural origin. Technical education had no popularity at all among Hindu Brahmans, notwithstanding the very high shares they held in other fields.[39] As we have seen, technical education in India may have been of a reasonable scale, but its quality was questionable from the comparative viewpoint of other countries' experiences. For instance, the pattern of patent application may provide a rough impression for such comparison. In the quarter of a century prior to 1929, the number of Indian applications for patents increased sharply from 550 to 1,400, but the latter figure was still only 10 per cent of the total number of patents granted in Japan for 1929, and 1.0 per cent of the number for the United States.[40] Moreover it should be noted that 90 per cent of the former 550 applications were filed by non-Indian residents in India (25 per cent) and foreigners (65 per cent).

Next we should like to touch in more detail upon the specific technical education of textile experts. Although the figures in Table II contain a number of textile-related institutions, many of them were small-scale weaving schools and textile institutes for vocational training, and not for fostering middle management staff for the modern mill. For the latter purpose, a mere dozen institutions were regarded as capable of satisfying the requirements even in the 1940s.[41] Only a few institutions, such as Victoria Jubilee Technical Institute, Bombay; Ranchhodlal Chhotalal Technical Institute, Ahmedabad; Kalabhavan Technical Institute, Baroda; Bengal Textile Institute, Serampur; Government Central Textile Institute, Kanpur, could provide training up to Diploma or Licentiate standard. And it is no overstatement to say that among these, Victoria Jubilee Technical Institute alone could provide the real training necessary for new middle management staff in the Indian cotton textile industry, considering the scales and histories of these institutes.

Victoria Jubilee started with three-year courses in cotton manufacture and mechanical engineering, and later expanded to offer four four-year courses in mechanical engineering, electrical engineering, textile manufacture, and technical

39 More precise information is available in the various quinquennial issues of *Progress of Education in India* [15].

40 The figure for 1929 is the number of patents granted. Five hundred and fifty is the annual average for the years 1893 to 1915. See *Report of the Indian Industrial Commission* [17, p. 175] and the *Indian Textile Journal* [9, Dec. 1931, p. 86].

41 See Section 3 of *Scientific Man-Power Committee Basic Report on Survey and Assessment* [20]. It also shows that engineering education was in a rather better situation, as reflected in the earlier replacement of foreign technicians.

chemistry to more than 100 students each year.[42] After passing their final exams, the students were qualified for a diploma or license in their respective subjects. But in the earlier period, the Institute had to battle to open the job-market in the Indian industries, hence the number of its graduates was quite limited. This led to a heated controversy over the effect and efficiency of Victoria Jubilee Technical Institute in the *Times of India* and the *Indian Textile Journal* around 1904. Yet the controversy indirectly resulted in encouraging some improvements in teaching method and application, and the strict selection of better qualified students.

The Report of the Atkinson-Dawson Committee uncovered the inadequacies in the system of apprenticeship for the technically trained, and urged the Institute to introduce six months outside practical work in the last year of the students' schooling. Thus the Institute improved step by step and established its name by overcoming the initial difficulties of lack of employment for its graduates and employers' complaints. In the 1940s, the majority of the newly technically trained in cotton mills were graduates of Victoria Jubilee Technical Institute. However, considering the huge size of the Indian cotton textile industry, the Institute alone was quite inadequate as a main supplier of technically trained middle management staff.

Although the institutional format was copied from the British educational system, technical education in India was far behind its model with respect to the scale and speed of its development. What is more, the Indian educational system was linked in various ways with Great Britain, as typically shown in the case of scholarships for studying abroad and the use of common exams for the certificate of the City and Guilds of London Institute. This was not necessarily advantageous to India, since the British government was not at all keen on promoting technical education when compared to the governments of other countries. These various factors contributed to the slow development and low quality of Indian technical education on the one hand, and intensified the heavy dependence upon British technicians and the British machinery industry on the other.

B. *Choice of Technique and Managerial Functions*

1. *Factors directly determining Mule replacement*

We now come back to the problem of Ring frame diffusion in order to clarify the real function of foreign staff in managerial decision-making in relation to technological choice. Our previous discussion of the problem has shown that, as far as macro analysis is concerned, the changes in Mule ratios were fundamentally ruled by the pace of replacement, which was not high because of the poor depreciation allowance policy. But problems still remained with this explanation, since some older mills continued to introduce Mule spindles to replace

[42] The electrical engineering and technical chemistry courses were opened in 1903 and 1906 respectively, and the sanitary engineering and plumbing course was introduced in the 1910s. The Institute was maintained by grants from the Bombay government, the Municipality, the Millowners' Association, and other memorial foundations.

TABLE III
CONTINGENCY TABLE FOR FOREIGN STAFF AND MULE RATIOS

Var. 4 (l)	MT				MT*				Total
Var. 3 (k)	MG		MG*		MG		MG*		
Var. 2 (j)	D	D*	D	D*	D	D*	D	D*	
H	11	3	2	1	2	3	5	15	(42)
Var. 1 (i) M	15	5	1	8	2	0	3	17	(51)
L	15	15	5	12	2	8	4	41	(102)
Total	(41)	(23)	(8)	(21)	(6)	(11)	(12)	(73)	((195))

Note: D, MG, and MT denote directors, managers, and masters, respectively.
* indicates absence of foreigners.

worn-out Mules, while some other newly erected mills adopted Mule spindles as well as Rings even after the 1890s. These unusual phenomena in a coarse yarn producing industry have to be explained in the light of managerial decision-making on the selection of Mules or Rings.

As pointed out earlier, the proportion of technically trained directors was extremely low. Boards therefore had to invite advice on technological matters from foreign technical staff who frequently had strong connections with the British machinery makers, and were themselves inclined to cling to their former experience of Mule operation in Great Britain. To confirm this conjecture, Mule ratios have to be examined in relation to the employment of foreign staff. For this purpose, the mill-based cross-sectional data of 1917 are adopted. They provide information on the Mule ratio and the foreign-native staff composition in top and middle management for each of 195 mills. The year 1917 is selected as it is the midpoint of the period under consideration, and falls prior to the start of the observed convergence of Mule ratios for different regions. The data sources are *Report of the Bombay Millowners' Association* [16], *Indian and Japanese Textile and Engineering Diary* [7], and *Thacker's Indian Directory* [22].

Firstly, each of the 195 mills is classified into one of three classes according to its Mule ratio, viz., either $1 \geqq H \geqq 0.50$, $0.50 > M \geqq 0.10$, or $0.10 > L \geqq 0$ (Variable 1, $i = 1, 2, 3$). As shown in the marginal totals of Table III, more than 20 per cent of all mills still installed more than half Mule spindles in 1917, although only a negligible proportion of Mule spindles was maintained in about half of all mills. Secondly, all mills are classified into another two categories, depending on whether foreign staff was included or not on the board of directors (Variable 2, $j = 1, 2$).[43] In 34 per cent of the mills at least one foreign staff member was included on the board. Thirdly, the mills are discriminated on the basis of

[43] Whether a managing agency is owned by foreign or native capital may be another alternative variable to be introduced. A managing agency owned by foreign capital necessarily included foreign agency directors, but even some mills managed by native managing agencies also had foreign directors. That is, the director-variable seems to be more comprehensive than the agency-variable, although the two are highly correlated.

whether the manager was a foreigner or a native (Variable 3, $k=1, 2$). Foreigners were occupying the manager's post in 42 per cent of all mills. Fourthly, the employment of foreigners in middle management is identified with respect to the positions of carding, spinning, weaving masters and engineers (Variable 4, $l=1, 2$).[44] Forty-eight per cent of the mills are found to have employed at least one foreigner in middle management.

All of this information is combined into the four-dimensional contingency table as shown in Table III. The contingency table can be expressed in a different way by the ANOVA type expression, i.e., the combination of the main effect and the interaction effect. The frequency of each cell (m_{ijkl}) is calculated as

$$\log m_{ijkl}=u+u_{1(i)}+u_{2(j)}+u_{3(k)}+u_{4(l)}+u_{12(ij)}+u_{13(ik)}+u_{14(il)} +u_{23(jk)}+u_{24(jl)}+u_{34(kl)}+u_{123(ijk)}+u_{124(ijl)}+u_{134(ikl)} +u_{234(jkl)}+u_{1234(ijkl)}\,,^{45}$$

for $i=1, 2, 3$; $j=1, 2$; $k=1, 2$; and $l=1, 2$.

This is equivalent to the so-called saturated model in a log-linear model analysis of the contingency table.

Now, our aim in analyzing the contingency table is to extract or to estimate the interaction effect of foreign staff and Mule ratio. This becomes possible by converting the saturated model into a non-saturated model with degrees of freedom. Specifically, the existence and contribution of such effects are roughly measured by the changes in the likelihood ratio test statistics through fitting the nested models. In the case of a four-dimensional contingency table, more than 150 log-linear models could logically be constructed, but the number can be easily reduced under reasonable assumptions. The hierarchy principle is first adopted as the most natural principle by which to construct models. Secondly, Variable 1, the Mule ratio, is interpreted as a kind of response variable, and our analysis is confined to finding the relationship between the response variable and other factor variables. In other words, except for the main effects and some interaction effects resulting from the hierarchy principle, the other effects are all related to the response variable.

Under these conditions, sixteen models were fitted, of which nine relevant versions are summarized in Table IV. The expected values of cell frequencies

44 In case of classifying staff into top or middle management, the manager is regarded as belonging to the latter. Yet his actual function lies, as a rule, midway between the two, hence they are separately treated in this analysis.

45 $u\equiv\frac{1}{IJKL}\sum_i^I\sum_j^J\sum_k^K\sum_l^L\log m_{ijkl}$; $u_{1(i)}\equiv\frac{1}{JKL}\sum_j^J\sum_k^K\sum_l^L\log m_{ijkl}-u$;

$u_{12(ij)}\equiv\frac{1}{KL}\sum_k^K\sum_l^L\log m_{ijkl}-u_{1(i)}-u_{2(j)}-u$;

$u_{123(ijk)}\equiv\frac{1}{L}\sum_l^L\log m_{ijkl}-u_{12(ij)}-u_{13(ik)}-u_{23(jk)}-u_{1(i)}-u_{2(j)}-u_{3(k)}-u$;

$u_{1234(ijkl)}=\log m_{ijkl}-u_{123(ijk)}-u_{124(ijl)}-u_{134(ikl)}-u_{234(jkl)}-u_{12(ij)}-u_{13(ik)}-u_{14(il)}-u_{23(jk)} -u_{24(jl)}-u_{34(kl)}-u_{1(i)}-u_{2(j)}-u_{3(k)}-u_{4(l)}-u$; and so on.

Other terms are similarly defined by changing the corresponding suffix. For more detail, see Y. Bishop et al., *Discrete Multivariate Analysis* [3].

TABLE IV
SUMMARY OF THE FITNESS OF LOG-LINEAR MODELS

Model	Terms Included	df	G^2	χ^2
(1)	$u+u_1+u_2+u_3+u_4$	17	111.42*	140.00*
(2)	$u+u_1+u_2+u_3+u_4+u_{12}+u_{13}+u_{14}$	12	101.31*	123.26*
(3)	$u+u_1+u_2+u_3+u_4+u_{12}+u_{14}+u_{24}+u_{124}$	11	74.99*	71.34*
(4)	$u+u_1+u_2+u_3+u_4+u_{12}+u_{13}+u_{23}+u_{123}$	11	68.70*	66.73*
(5)	$u+u_1+u_2+u_3+u_4+u_{13}+u_{14}+u_{34}+u_{134}$	11	53.10*	55.61*
(6)	$u+u_1+u_2+u_3+u_4+u_{12}+u_{13}+u_{14}+u_{23}+u_{24}+u_{123}+u_{124}$	6	36.98*	43.11*
(7)	$u+u_1+u_2+u_3+u_4+u_{12}+u_{13}+u_{14}+u_{24}+u_{34}+u_{124}+u_{134}$	6	20.06*	30.85*
(8)	$u+u_1+u_2+u_3+u_4+u_{12}+u_{13}+u_{14}+u_{23}+u_{34}+u_{123}+u_{134}$	6	10.07	12.35
(9)	$u+u_1+u_2+u_3+u_4+u_{12}+u_{13}+u_{14}+u_{23}+u_{24}+u_{34}+u_{123}$ $+u_{124}+u_{134}+u_{234}$	2	0.19	0.37

Note: * denotes the significant value in the upper 5 per cent tail of the corresponding χ^2 distribution with degrees of freedom as indicated.

($\hat{m}_{ijkl}$) were calculated by the iterative method of Maximum Likelihood Estimation for Model (9) alone, and all other estimates in Models (1)–(8) are obtained by simple direct calculations from their sufficient statistics. The Pearson's chi-square statistics (χ^2) is given to judge the fitness of models. Also, the likelihood ratio test statistic (G^2) is provided to select the models or to find the effect of interaction terms, since it has a nice property of monotonicity for a nested hierarchy of models.

From the estimated results in Table IV, the following implications can be drawn. As shown in Model (1) and its χ^2, the complete independence of the four underlying variables does not hold in our case. That is, the Mule ratio clearly does have some interaction with other dichotomous variables of foreign staff employment. The poor fitness of Model (2) with three first-order interaction terms means that none of the separate interactions of the three factor variables with the Mule ratio suffice to explain the whole interactive relationship among the underlying variables. This result also implies by the G^2-monotonicity for nested models that any conditional independence does not hold with respect to $u_{12}=0$, $u_{13}=0$, $u_{14}=0$ and their combinations. Both groups of models with one and two first-order interaction u-terms were calculated, but are deleted from Table IV to save space.

Model (8) has a rather high goodness of fit, hence, as a matter of course, so does Model (9), which is the highest model in the hierarchy, with only one deleted term: $u_{1234}=0$. The result of the fitness of Model (8) implies a three second-order interaction term model being equally acceptable for the same reason as above. From the comparison of Models (6), (7), and (8), we can obtain interesting findings on the functions of foreign staff in different posts. Compared with corresponding two second-order interaction terms jointly for these models, the role of Variable 3 has a greater effect as a catalyzer than do Variables 4 and 2. In other words, the Mule ratio is greatly affected, not directly by the presence of foreign staff at one level only, but by the joint presence of foreign staff at more than one level, such as a foreign manager and a foreign master or a foreign manager and a foreign director. In such cases, the consolidating effect of a manager was greater than that of a director or a master.

This finding is equally endorsed by comparing a two second-order interaction terms model with its corresponding one term model, such as Model (8) vs. Model (4) or Model (7) vs. Model (3), since these comparisons give us a rough measure of the G^2 reduction effect for the terms u_{134}, u_{123}, and u_{124}. Accordingly, what is drawn from our model fitting is that the high Mule ratio is definitely related to the mediating function of a foreign manager combined with the presence of other foreign staff in the mill. Or in a weaker expression, it can be said that the joint presence of foreign staff in both top and middle management is reflected by a high Mule ratio. A mill with no foreign staff was, conversely speaking, apt to have a lower Mule ratio, as is immediately apparent from Table III.

The above conclusion reconfirms the previously posited linkage and inclination of foreign technicians towards British textile technology. Two remarks are best added. First, typical examples of this relationship between Mule ratio and foreign staff are most plentiful in the mills of the United Provinces, such as Cawnpore Cotton, Muir, Elgin, Agra Spinning & Weaving, and the affiliated John's mills, all of which, without exception, had both high Mule and foreign staff ratios. Although other examples can also be pointed out in Bengal, Bombay City, and so on, the high degree of concentration in a specific region is a unique Indian characteristic requiring studies from different viewpoints.

Secondly, it may be worthwhile to mention that twenty-six mills out of the forty-two Mule-dominated mills were of the noncombined type (i.e., spinning alone). This fact might suggest the significance of the financial factor, since financial difficulties were said to be in general much more serious for noncombined mills. Moreover, the noncombined mill was itself a typical style of British mill management, hence they normally included many foreign managerial staff as well. Whether there exists any circular relationship between British-style management and financial difficulties or not is another interesting problem to be examined separately. So far, by means of cross-sectional micro data we have confirmed that a high Mule ratio is related to the high foreign staff ratio in Indian mills. Consequently we are again drawn back to the problem of why the Indian cotton textile industry had to depend so heavily on foreign staff for such a long time.

2. *Indian directors and the technically trained*

The problem can be regarded in essence as the problem of Indian directors, in the double sense that they failed to train themselves to perform the functions served by foreign staff, and were disinclined to create the internal labor market for technically trained middle-management staff. It is entirely to be expected that the knowledge of long-staying foreign staff in India should gradually become outdated, whereas short-stayed staff (essentially mercenaries) were indifferent to technological improvements. These factors, therefore, might be indirect causes for the slow diffusion of Ring frames and the slow development of Indian textile technology. But the key factor consisted in the incompetence of directors, who were, after all, unable to overcome those defects for a long time.

As previously mentioned, those directors possessing adequate knowledge of textile technology were merely a small fraction of all directors (cf. footnote 31). All of the knowledgeable were Parsis, and not a few obtained their know-how from on-the-job training. According to the directories of the textile industry, the proportion of directors with higher education was, to our surprise, fairly small even in the 1940s. This stands in sharp contrast to the experience of Japan,[46] where almost all directors had higher or professional education. Many Indian directors had only had private education outside the school system, and this might lie behind their distrust of or antagonism towards formal school education and the educated.

In the 1890s, nearly 40 per cent of all university students were drawn from the handful of privileged in the population, i.e., the Hindu Brahmans. They had a strong preference for arts colleges, and only a few per cent of them were interested in studying at engineering colleges. By contrast, one-fifth of European or Anglo-Indian students in India studied at engineering colleges in the earlier period, although their preferences were gradually diversified in subsequent years. An important fact to be mentioned in the present context is that even Parsis' sons did not choose engineering colleges or science studies at arts colleges. This indirectly implies that professional studies at the higher education level were regarded as unnecessary for future top management positions. This conjecture is distinctly endorsed by the Report of the Atkinson-Dawson Committee, whose interviews revealed that there existed no job-openings at all for engineering college graduates or those returning from engineering studies abroad.

In fact it was almost impossible to find any engineering college graduate employed in cotton textile mill management. In Japan, a lot of professional college graduates were employed by cotton textile mills and started their careers from the lower posts of middle management. Promotion of the highly educated to top management took place even in *zaibatsu*-related mills. Thus, in the Indian situation mill management was not conducted by promoted professionals, and the implication is that the separation between ownership and management in India was simply the external result of the directors' lack of knowledge of textile technology.

The Report of the Atkinson-Dawson Committee points out the further interesting fact that many agency directors and managers, particularly Europeans, expressed strong dissatisfaction with technically trained graduates on the grounds that they were neither sufficiently disciplined, nor inclined to do the dirty jobs with their own hands. And not a small portion of the technically trained were not regarded as being sufficiently competent for their posts. These criticisms might have some validity because of the elite consciousness of the graduates and the shortage of apprenticeship training. But it should be remembered that Euro-

46 See *Handbook of Textile Industry* [6]; N. N. Desai, comp., *Directory of Ahmedabad Mill Industry* [5]; Y. Aonuma, *Nihon no keieisō* [The management class in Japan] [1]; and H. Morikawa, *Gijutsusha* [Engineers and technologists] [13].

peans were in effect their competitors, while agency directors were almost always on the side of the jobbers in the frequent confrontations between jobbers and technically trained newcomers. Although we are not in a position to disprove their criticisms of the technically trained, it is instructive that the more conservative senior management staff were towards technical innovation, the more severe were their criticisms of technically trained graduates in the Report.

Just as shortages of disciplined workers are due to defective labor management, so too is the insufficient discipline of the technically trained due to defective top management. Their main managerial aim was not to train young technical staff within a mill, but to strive to employ cheaper managers and masters without themselves understanding a bit of textile technology. It was true that only a few institutions, such as Victoria Jubilee Technical Institute, could supply really qualified technical cadres, whereas many others failed to realize it for a long time. Yet, to develop technical education and to foster graduates for industry are extremely important from the long-run managerial viewpoint, since sufficient technical knowledge is indispensable for the rapid progress of industry. However, technical education is not a sufficient condition for such rapid development, nor is it able to itself create jobs for its graduates.

Thus it was crucial that there existed no internal labor market for young middle management trainees graduated from technical institutions. This is partly owing to the distinct segregation between the top and middle management classes in India. In other words, promotion possibilities from middle to top management were entirely absent, as is reflected by the high turnover rates of middle management staff. For instance, in the first half year of 1933, ninety persons in middle management positions had changed or newly obtained posts in other mills.[47] This means more than a 15 per cent rate of turnover or a job-change for every two terms of contract, which can be described as an unstable market for the technically trained. As the result of such segregation, almost no board of directors contained any promoted staff among its members. This kind of closedness and isolation of top management society was the very soil which resulted in the slow technological development in India. Furthermore, the roots of the disease went deep in the sense that it was an exact reflection of the various sorts of social segregation and heterogeneity in Indian society as a whole.

IV. CONCLUDING REMARKS

Finally, let us briefly summarize the results of the above discussion. As regards technological adaptation in the Indian cotton textile industry, the introduction of new information on technological innovations was, as a rule, rather quick and early because of the strong connections with the British industries. Compared with other latecomers' experiences, the first adoption dates of major innovations were not very late either, but the subsequent diffusions were ex-

47 See the *Indian Textile Journal* [9, Aug. 1933, p. 401]. The turnover rate of foreign technicians appeared to be lower than it. In those days many of them were long-stay or second-generation foreigners.

tremely slow. Two main causes for the slow diffusion were pointed out, namely, the regionally fragmented market and certain managerial defects. The latter aspect, which was thought to be more crucial and partly a cause of the former, was examined statistically in greater detail for the case of Ring frame diffusion.

A regression analysis based on time-series macro data confirmed the existence of regional differences and the significance of replacement investments as a ruling factor in the changes in Mule ratios. Although the results were entirely consistent with our previous analysis of the poor depreciation allowance policy followed by the managing agencies, the unreasonable behavior involved in continued installations of a disadvantageous machine, the Mule, had to be explained through other reasons. A log-linear model analysis for the contingency table compiled from cross-sectional micro data provided the clarification that the high Mule ratio reflected the joint presence of foreign staff in both top and middle managements supported by the mediating function of a foreign manager.

This analysis confirms the important role of foreign technicians in the decision-making on choice of technique. The high dependence on foreign staff was directly related to the fact that most directors had insufficient knowledge of textile technology. While not all foreign technicians were adequately competent, they had, with few exceptions, strong connections with the British industries. This meant they were generally inclined to stick with old but familiar technology based upon their experience in Great Britain. The diffusion of Ring frames was often discouraged by these factors, as well as by the small size of depreciation funds. In short, technological adaptation in India was greatly influenced by the British experience and by British patterns of technological development, since the main channel for technology information in India was of the so-called "human-embodied" type, the specific embodiment being British technicians and engineers.

The high dependence on foreign technical personnel was almost unavoidable partly because of the slow development of domestic technical education. The replacement of foreign staff with technically trained natives progressed gradually in parallel with the increase in graduates from technical institutions. Indian technical education for a long time suffered both from an inability to supply sufficiently qualified graduates and from the stagnant demand for them as well. Such problems mainly originated from the absence of the internal labor market for middle management, which was completely segregated from top management. Thus there existed many difficulties which could only be overcome by the efforts of the Indian directors themselves.

Two further implications from our analysis should be mentioned. First, the impression appears to prevail in India that all cotton textile mills managed by British capital or directors were habitually equipped with the most modern technology. This impression is not necessarily groundless, since some of the major innovations were first introduced by just such mills involving British capital. The Connaught Mill was the first complete Ring mill, the Finlay Mill was first to introduce the electric drive, the Buckingham & Carnatic Mills first with the automatic looms, etc. And yet the view is not correct, as is shown by the above analysis of Ring frames. Not a few such mills often faced financial difficulties and were liquidated. On average they were apt to stick to conventional technology.

Secondly, it is occasionally proclaimed by chauvinists that the development of technical education in India was retarded by the colonial plots of the Home Government, namely, the low standard of technical education making it easy to exploit India without encountering keen competition. Insofar as technical education is judged from the economic aspects, this view is difficult to sustain, particularly when we are reminded of comparisons with non-British areas of India, and of the relative backwardness of British technical education itself.[48] While it cannot be denied that the government was not especially eager to advance technical education in India, the Indian top management class has to share the responsibility as well for not having promoted technical education in real earnest by encouraging a more open and meritocratic society in the industrial world.

[48] See, for example, G. W. Roderick and M. D. Stephens, *Education and Industry in the Nineteenth Century* [18].

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