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THE DIFFUSION OF NEW TECHNOLOGIES IN THE JAPANESE SERICULTURE INDUSTRY: THE CASE OF THE HYBRID SILKWORM*

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I. *Introduction—The Japanese Sericulture Industry and Its Technological Development—*

It is broadly recognized that raw silk and silk fabrics were the most important exportable goods in the earlier stages of industrialization in Japan. The export of silk and related goods had accounted for nearly half of total exports up to the end of the 19th century. Although the proportion gradually decreased in subsequent years because of the diversification of export goods resulting from the development of other industries, the significance of the sericulture industry in exportation continued to be maintained up to the end of the 1930's. As is well known, the export of Japanese raw silk, which surpassed that of Chinese around 1905, continued to increase greatly in the 1910's and 1920's and Japan remained the largest exporting country in the world market.

Nowadays it is commonly understood that the rapid progress of the Japanese sericulture industry was achieved mainly through continual technological innovation as well as rationalization of the production organization. The prevailing reeling machine was a typical example of appropriate technology, combining the transplanted steam-reeling machine with the indigenous hand-reeling one. It was further improved step by step on various parts, and remodelled into the so-called multi-end reeling machine in the 1920's. The cocoon dryer and cooking machine were equally improved considerably and contributed to increasing productivity. These developments in filature technology and the expansion of the industry also required increases in cocoon production and the improvement of cocoon quality.

The first of these requirements was largely fulfilled by the rapid progress in summer-autumn rearing after 1900. The second one was met by the epochal development of the first filial (F_1) hybrid silkworm in the mid-1910's. That is to say, the increase in production and improvement in the quality of cocoons were the results of remarkable technological changes achieved through domestic R&D activities rather than through the imported innovations. It is in fact no overstatement to say that the development and rapid diffusion

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of F_1 hybrid silkworms were the most important and most epoch-making innovation in the history of technological development in the Japanese sericulture industry. To examine closely the socio-economic background of the birth of the F_1 hybrid, and also to determine the dominating factors in its rapid diffusion, are the main purposes of our present analysis.

This problem-raising will cast light upon the following two important aspects. First, the diffusing speed of F_1 hybrid silkworms was extremely high, compared with other countries' experiences as in the famous example of hybrid corn in the United States.[1] It took more than a quarter of a century to complete the diffusion of hybrid corn, despite its much later commencement, whereas the diffusion of the F_1 hybrid silkworm in Japan was almost completed within merely ten years. At various parts in Japanese economic history, it is easy to observe new technologies achieving very rapid diffusion. In other words, this rapid diffusion of technological innovation appears to be one of the unique and important characteristics of the Japanese economy. Our analysis of the F_1 hybrid silkworm will help us to understand the general features of technological diffusion in Japan, which remains inadequately studied despite the important role it played in promoting Japanese economic development.

Secondly, our analysis may raise doubts about the conventional appraisal of prewar government agricultural policies, which argues that the introduction of new technology was almost compulsorily implemented under the authoritarian guidance of the Government.[2] Much of the evidence in our analysis suggests that it was the active response of a wide range of both large and small cocoon producers to the new technology that was the key factor to the rapid diffusion of F_1 hybrid silkworms. It provides an answer to the question of whether such centrally imposed bureaucratic guidance was really the unique force in the promotion of rapid diffusion. Although the negative effects of the systematic network of experimental stations have been so far emphasized as an aspect of the so-called "industrialization from above" in economic history, its great positive effect in encouraging local response in the process of diffusion should not be disregarded. Besides, our study of R&D activities and sericultural education in the private sector may reveal some significant characteristics of the diffusion of agricultural technologies *vis à vis* manufacturing technologies.[3]

Finally the statistical data adopted in our analysis are to be briefly mentioned. The main period under consideration is the year from 1914, the date marking the first distribution of the parent-eggs for F_1 hybrid silkworms, to 1929, from which time new types of hybrid varieties became prominent after the completion of the diffusion of basic F_1 hybrids. The

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1 For more detailed information, see Z. Griliches, "Hybrid Corn: An Exploration in the Economics of Technological Change," *Econometrica*, October 1957, and also the references cited by him. In the case of spring rearing varieties of F_1 hybrid silkworms, the entire replacement of indigenous varieties was completed within several years.

2 For examples of this kind of study, the reader is referred to M. Uchiyama, *Nōgyō no kairyō fukyū ni kansuru bunken, shiryō, sono kaisetsu* [Reference Works and Data Pertaining to the Improvement and Diffusion of Agricultural Technology, with Annotations], National Research Institute of Agriculture, 1950. His monograph is a precious one in this field, although we do not share his negative appraisal of the diffusion network organized by the Government.

3 Hybridization technology is considered here to belong to agricultural technology which is embodied in the growing process of organic systems or organisms. The main characteristics of the diffusion of manufacturing technology have also been analyzed for the case of a major innovation in silk-reeling technology, the multi-end reeling machine. For a comparison, see Y. Kiyokawa, "Seishi gijutsu no fukyū-denpa ni tsuite" [On the Diffusion of Silk-reeling Technology], *Keizai kenkyū*, Vol. 28, No. 4, October 1977.

most important information is available in the annual report *Sangyō torishimari jimuseiseki* [Statistical Annual of Pébrine Inspection of Silkworm-eggs], published by the Ministry of Agriculture and Commerce during the above period.[4] Special attention will be paid to the years 1917–23, which proved to be of critical importance for the diffusion of F_1 hybrids and for which the statistical information is most abundant. Thus probit analysis shall be applied to the cross-section data for the year 1918, when the variation in diffusion rates among the various prefectures was still wide enough to extract the factors determining the diffusing speed of F_1 hybrid silkworms. Some other statistics from the same Ministry will be supplemented for the probit analysis.

Prior to the quantitative analysis, Section I will first confirm the historical background to hybridization in the Japanese sericulture industry. The broad and strong tradition induced the integration movement of cocoon varieties which subsequently produced two important bases for the rapid diffusion of F_1 hybrid silkworms. These were the network of sericulture experimental stations and the active involvement in the silkworm-egg production industry of big silk-reeling filatures. In Section II, the factors determining the diffusion of the F_1 hybrid, which was absolutely superior to the indigenous varieties, shall be grasped by probit analysis. This will show the significance of big silk filatures' initiatives and also the important role of technical education and R&D activities. Finally, actual activities in the relevant fields will be examined to endorse the effects extracted by the statistical analysis.

II. *The Birth and Diffusion of the F_1 Hybrid Silkworm*

A) Improvements in Silkworm Varieties and the Establishment of a Diffusion Network

1. The Historical Background to Hybridization and the Role of Silkworm-egg Producers

The Japanese sericulture industry had a long-standing tradition of crossing silkworms, although it was not until the early 1910's that the mass-production of F_1 hybrid silkworms was developed for practical use, since the crossing had to realize the heterosis (i.e. hybrid vigor) based upon the scientific rigorousness of heredity in accordance with Mendel's Law. One of the oldest written records in existence shows that a hybrid between spring and summer rearing silkworms had been produced and had gained a high reputation in Nagano Prefecture as early as 1845.[5] The existence of vernacular terms for crossing or hybridization in various parts of Japan endorses again that the cross-breeding of silkworms was already widespread practice in those days in Japan. The crossing of summer varieties was for a time proscribed by the Silkworm-egg Control Ordinance of 1873. When this restriction was lifted in 1878, the practice was said to have revived quickly and, for instance, eight different cross-breeds were already listed at the Yokohama Cocoon Sample Fair held in the

[4] Prior to 1918, the Japanese title was slightly different, viz. *Sangyō torishimari seiseki.* After 1922, the Ministry was reorganized and called the Ministry of Agriculture and Forestry.

[5] See p. 53 of *Shinano sangyō enkaku shiryō* [Historical Data on the Development of Sericulture in Shinano], Ueda, 1892, by R. Takashima. *Dainippon san-shi* [Sericulture History of All Japan], Tokyo, 1898, by A. Sano, dates this event to 1767 (pp. 24–29).

following year, 1879.[6]

This strong interest in improving silkworm varieties by cross-breeding continued to manifest itself thereafter in the frequently changing popularity of different silkworm strains. These changes first began to occur in the early Meiji period, when small cocoons of pale-green varieties (e.g. *Seihaku*) were preferred, since they were relatively easy for sericulture farmers to rear. In the 1880's, large white cocoons (e.g. *Akajuku, Onichijimi*) came into favor, enjoying their greatest vogue at the end of the decade. But the small cocoon variety (this time, *Koishimaru*) then staged a comeback and was fashionable until the end of the century. After the turn of the century, medium-sized cocoons such as *Aojuku* and *Matamukashi* had gradually come into prominence and remained in widest use up to the early Taishō period, i.e. the starting time of the first filial hybridization. It is not surprising that a number of outstanding improved varieties were produced through cross-breeding in the course of these frequent changes in preferences. Some of the more famous examples of such hybrids are *Sekai'ichi* (the *Aojuku* line), *Hakuryū* (the *Koishimaru* line), *Shiratama* (the *Matamukashi* line), etc., all of which spread throughout Japan. It should be equally noted that a great many hybrids were developed at the prefectural level in response to local conditions and circumstances.

On the other hand, the race improvement of native varieties by crossing with foreign races was attempted from a comparatively early date. Foreign silkworm eggs were imported by the Hokkaidō Cultivating Commissioner in the early Meiji period, although the attempt to rear them never went much beyond the experimental stage. In the second half of the 1880's the Ministry of Agriculture and Commerce actively imported Chinese and some other foreign varieties and, after their own experimental rearings, distributed them to some sericulture educational institutions and egg-producers. This attempt was said to have provided a tremendous stimulus to many egg-producers and sericulture farmers, as is shown by the fact that a number of excellent Sino-Japanese hybrids were produced in the 1890's by progressive producers in the main sericulture areas. For instance, typical hybrids of the type were *Tsunomata*, developed in Ibaragi and Tochigi prefectures, *Kakushina* from Kanagawa, *Shinamata* from Fukushima, *Round-matamukashi* from Saitama, etc. Meanwhile a sericulture expert at the Yokohama Raw Silk Conditioning House, N. Imanishi, brought an Euro-Chinese hybrid back with him from Italy to open the way for the rearing of European races. The Sanryūsha Co. of Aichi Prefecture, to which he gave the hybrid, successfully developed by selective breeding the first Euro-Japanese hybrids, *Kōsekimaru* and *Sanryūmata*, which were said to be better adapted to the climatic conditions in Japan.

It, however, is very important to bear in mind that none of these hybrids were the so-called F_1 hybrid in the strict sense. In almost all cases, such hybrids should be considered simply as a kind of fixed strain amplified through cross-breeding technique rather than the non-repeatedly reproduced generation from the pure parent eggs. As is occasionally pointed out, silkworm-egg producers kept hold of the F_1 hybrid with heterosis to use as parent eggs, and the F_2 or subsequent generations were sold to sericulture farmers mainly because of easier successive reproductions. Consequently there existed two opposing appraisals as to the quality of these hybrid cocoons among sericulture farmers and silk-reeling filatures.

[6] See pp. 276–77 in Volume 3 (Silkworm-egg History) of *Nihon sanshigyō-shi* [A History of Japanese Sericulture], Dainippon Sanshi-kai, 1936. This volume discusses also in detail the changes in popular varieties of cocoons.

One was a favorable view on the variety improvement by cross-breeding, for which stable lines of hybrid, selected out after years of careful experimental rearings, were involved. The other view, widely held among sericulture farmers,[7] evaluated the technique negatively, since the hybrid silkworms frequently produced bad crops owing to the instability of their characteristics.

This divergence of opinion was closely related to the fact that the hybridization technique of the Meiji period was never supported by the heterosis theory of F_1 hybrids based upon Mendel's Law. The F_1 hybrid can realize the dominance, viz. the better qualities of both parents through heterosis, whereas the recessives are inevitably recovered in the second or subsequent generations. Accordingly it was quite natural from a genetic point of view that easy hybridization which did not follow the exact procedures of cross-breeding for heterosis was inclined to encourage the proliferation of inferior silkworm varieties. However, despite the existence of opposing viewpoints and results, what should be emphasized is the competitive nature of egg-production market and the existence of vigorous enterpreneurship which led to continual efforts to improve existing varieties and gave the market its special dynamism. More specifically speaking, it was the progressive silkworm-egg manufacturers who promoted the technical education and established the diffusion network, both of which had not fully been existed in the society in those days. Hence one cannot correctly appraise the significance of conventional improved-varieties without taking account of this basic fact.

In the second half of the 19th century, educational and diffusion activities related to sericulture technology were organized almost exclusively by the producers of silkworm-eggs. Hence the rapid development of the Meiji sericulture industry owed a great deal to the promotional efforts of these egg-manufacturers. Since agro-sericulture schools and vocational centers were not set up on a systematic basis by the authorities until after the turn of the century, and even then the instruction offered in such institutions mainly aimed at giving specialized training to agricultural school teachers and lower techno-bureaucrats, not at giving practical guidance for the improvement of agro-sericultural technology. Thus the active initiative of enlightened egg-producers, assisted by veteran sericultural farmers, was actually responsible for filling this gap. They provided broad technical guidance closely tied with production, and promoted the diffusion of new technical knowledge through educational activities at the local level.

Two typical examples of this kind of egg-manufacturer *cum* dealer are the Takayama-sha Co. of Gunma Prefecture and the Kyōshin-sha Co. of Saitama, both of which contributed substantially to the spread of warm-room-rearing techniques. From the early Meiji period, these two companies sent a number of sericultural instructors to study-circles and organized lecture sessions in various parts of the country. Moreover they set up technical training centers on their own sites and turned out a large number of sericultural experts through their intensive courses. By 1892, at least 6,000 of these technicians had already been trained, and by 1907 the number of graduates is reported to have reached 40,000.[8] Several other

[7] See, for example, *Honpō ni okeru ichidaikōzatsu sanshu hasshō-shi* [The Origin of the First Filial Hybrid Silkworm in Japan], Ichidaikōzatsu Sanshu Hasshō Kinenkai, 1928, pp. 2 and 57.

[8] See T. Konishi, *Sanshigyō no tenkai-katei ni okeru gijutsu no shinpo ni kansuru kenkyū II* [On Technological Progress in the Development of the Sericulture Industry, Part II] (mimeograph), Kyoto Sen'i Kōgei Daigaku, 1960, p. 50.

outstanding training centers were also established by private interests in various prefectures, such as Shimane, Yamaguchi, Okayama, Tokyo, etc.[9] All of these centers greatly contributed to improving the technical standards of sericultural farmers. This does not mean of course that there were no problems about the quality of graduates produced or no difficulties caused by excessive competition in the egg-production market, but there is no doubt that during the Meiji period the egg manufacturers themselves played a leading and decisive role in diffusing new technical knowledge about silkworm breeding and rearing.

2. The Dawn of "Experimental Station Technology"

It should be noted that more than just a matter of the dealers' sales promotion policies, there existed fully justifiable reasons requiring their animated activities of variety improvements. Since distinctly superior varieties of silkworms had not yet been developed at this time, and the quality of silkworms had yet to be improved through adaptation of the various varieties to regional climates and geographic conditions. In particular the summer-autumn rearings frequently produced bad crops, and the diffusion of improved varieties was still incomplete. The development by trial and error of appropriate varieties for stable crops was badly needed. Thus it was entirely reasonable that silkworm-egg producers should experiment with the breeding and rearing of different varieties.

On the other hand, cross-breeding and variety improvement gave rise to many new varieties of silkworm, and led to great diversification of varieties in various parts of Japan. This trend, coupled with changing preferences for specific varieties, produced wider variations in cocoon quality. Although precise time series data on the types of cocoons produced during the Meiji period are not available, even the fragmentary evidence makes it quite clear that a very large number of varieties were being reared all over Japan. For instance, 102 different types of cocoon were presented at the Yokohama Sample Fair of 1879, and at the third Domestic Industrial Exhibition in 1890, 144 varieties of cocoon were placed on display.[10] It is thus safely supposed from supplementary data that at least eight hundred separate types of cocoon were then being produced in Japan. In fact a national cocoon survey conducted by the Ministry of Agriculture and Commerce in 1904 endorses our conservative estimate by giving a figure of 1,593 for the number of cocoon varieties in existence.[11]

As might be expected, the existence of such a large pool of silkworm varieties could not avoid inviting the suggestion that the multiplicity of varieties should be sorted out and standardized. As early as the 1890's apprehensions had already been expressed over the extreme diversification of varieties of silkworm. Meanwhile the uniform quality in Japanese raw silk was more strongly demanded with the rapid expansion of raw silk exports. It was, therefore, maintained by silk-reeling filatures that the greatest single reason for the uneven and unstable quality of raw silk was ultimately the production of so many different kinds of cocoon. This view needs to be somewhat discounted, since it reflected the overwhelming

[9] Around 1890, there existed 325 sericulture training centers in 29 prefectures. See pp. 822 and 919 in Volume 3 of Nōrin Kyōkai, *Nōrin gyōsei-shi* [An Administrative History of Agriculture and Forestry], Tokyo, 1958.

[10] *Kyōshin-kai* [Sample Fairs, Trade Fairs] and *Hakuran-kai* [Industrial Exhibitions] were quite frequently held in various prefectures, and played a very important role in promoting the diffusion of new information and technologies.

[11] See *Nihon sanshigyō-shi,* Vol. 3, pp. 319–21. However, *Nōrin gyōsei-shi* puts the number of varieties at 1,003 (Vol. 3, p. 893).

negotiating power of silk-reeling filatures over sericulture farmers in the purchase of cocoons. The variation in quality of different cocoons was in fact not necessarily as great as the number of varieties would suggest, since essentially the same variety might be assigned different names. Nevertheless, one cannot deny that there existed too many varieties of silkworms, and that not a few of them were reared merely on a small scale.

Under these circumstances the Government could no longer defer a radical reform of its silkworm-egg policy. The immediate stimulus for the change was said to be strong pressure from silk-reeling filatures experiencing the drastic fall in raw silk prices of 1907. But there already existed the two basic underlying factors which dominated the direction of government policy. First, the indispensability of control and management of the parent and grandparent eggs of F_1 hybrids was gradually being realized, as the overwhelming superiority of F_1 hybrids produced by application of the Mendelian heterosis theory was steadily established. The second factor was the independent establishment by local governments of silkworm-egg breeding stations to improve and standardize existing silkworm varieties. It was against this background that the Government decided in 1911 to open the National Institute of Silkworm-egg Production and to enact the Sericultural Industry Law.[12] It was the dawn of the "experimental station technology" era after the previous age of "silkworm-egg dealers' (producers') technology."

In other words the government policy until this time had been essentially passive towards the rapid development of the sericulture industry. This characterization can be easily confirmable from the conservative nature of the laws and ordinances successively enacted in this field. For instance, following the Silkworm-egg Control Ordinance of 1873, the Government passed the Silkworm-egg Inspection Act (1886) to strengthen control over pébrine infected eggs. It was developed in subsequent years into the enactment of the Silkworm-egg Inspection Law (1897) and the Silkworm Disease Prevention Law (1905). All of these were designed primarily to control and prevent pébrine, not to encourage the improvement of cocoons and silkworm-eggs. After the 1905 Law, the radical change in policy came about and a more positive policy was adopted to develop the sericulture industry. This change was said to have been based upon the advice of the All Japan Raw Silk Association in 1909 and the Inquiry Committee for Production Survey in 1910. At the same time, it was the inevitable result of the fact that the level of breeding techniques had reached the point where breeding and its R&D activities could no longer be left to the egg producers alone.

While the role of vested interests and pressure groups in influencing the drastic turnabout in sericultural policies should not be dismissed lightly, special importance must be assigned to the bold initiatives and advices provided by the techno-bureaucrats and sericulture academics who were members of the authorities concerned or their advisory committee. This can, for instance, be observed from the fact that the National Institute of Silkworm-egg Production immediately started research on F_1 hybrids which was still at an

[12] Compared to the earlier legislation, e.g. the Silkworm Disease Prevention Law, etc., the new Sericultural Industry Law greatly strengthened the authority of the ministers and governors concerned, and actively promoted as well various other measures, such as a licensing system for the firms producing and refrigerating silkworm-eggs, tighter control of the markets for silkworm-eggs and cocoons, the establishment of a federation of producers' cooperatives and cocoon inspection committee to realize better selection and control of silkworm-eggs, etc.

exploratory stage in universities, and prepared the institutional network for distributing the parent eggs of F_1 hybrids, as soon as the Institute was set up. This was particularly significant when we bear in mind that the superiority of F_1 hybrids and their great practical utility had only been demonstrated in strict genetic terms a few years earlier. That is, K. Toyama, an authority on insect genetics, had repeated experiments in crossing Thai and Japanese silkworms in Bangkok, where he was temporarily in office as head of the Raw Silk Bureau of Thailand's Ministry of Agriculture and the Royal Thai School of Sericulture. It was in 1904 that he succeeded in confirming the applicability of heterosis by Mendelian Law to silkworms as well. This research, following closely on the rediscovery of Mendel's work in 1900, was a pioneering achievement in the early practical application of the theory, and even today is highly appreciated in the world of genetics.[13]

Upon his return to Japan in 1905, Toyama organized lecture series throughout Japan, and wrote enlightening essays in industrial journals in order to disseminate as widely as possible the distinct advantages of "the F_1 hybrid by itself." Meanwhile, through his scholarly contributions to academic journals and in his own works, he provided sericultural specialists with valuable information enabling them to deepen their scientific understanding of crossing. On the other hand, the high level of technical expertise and insight held by the specialists in the authorities concerned ought equally to be emphasized. That is to say, once the practical value of this technique had been properly analyzed and evaluated, T. Kagayama and his colleagues energetically set about applying the heterosis theory to the practical ends of the industry. More specifically speaking, the National Institute of Silkworm-egg Production, founded in 1911, began experiments in hybridization at once under the technical guidance of Toyama, aiming at the distribution within three years of the first parent eggs of F_1 hybrids.

In addition to the high professional competence of the central government's sericultural experts, there was another tendency which exerted a telling influence on the reorientation of the state's silkworm-egg policy. It was the establishment of local government egg-breeding station prior to the central one, aiming at distributing their own silkworm-egg sheets to producers and sericulture farmers in order to improve and standardize silkworm varieties at the local level. Tottori Prefecture, which was active from early on in improving varieties, set up the first local government silkworm-egg breeding station in 1903. It was followed in the effort by Shimane in 1905, and in 1906 by Tokushima and Shiga prefectures. Seven other prefectures, viz. Miyazaki, Yamaguchi, Kanagawa, Niigata, Hokkaidō, Chiba and Kumamoto, had independently started producing and distributing local varieties of silkworm-eggs prior to the establishment of the National Institute in 1911. For more detail information, the reader can refer to the *Sanpinshu ni kansuru chōsa* [A Survey of Silkworm Varieties], but those eggs distributed by local stations were, as a rule, of indigenous fixed strains already well-adapted to the local conditions and prevalent in each region. Typically popular varieties of such types were *Matamukashi, Improved matamukashi* and *Aojuku* of the univoltine strain, and *Ōkusa, Hakuryū* and *Aojuku* of the bivoltine strain.[14]

[13] See, for example, N. Takeuchi (ed.), *Toyama Kametarō kinen-roku* [Memories of Dr. K. Toyama], 1940 and T. Yokoyama, "Sanshi gijutsu no hattatsu-shi (7)" [A History of the Development of Sericultural Technology, Part 7], *Sanshi kagaku to gijutsu* [Sericulture Science and Technology], May 1965.

[14] See Nōrinshō (ed.), *Sanpinshu ni kansuru chōsa* [A Survey of Silkworm Varieties], Sanshi Dōgyōkumiai Chūōkai, 1921, pp. 78–82.

In parallel with the establishment of the National Institute of Silkworm-egg Production, the creation of prefectural egg-breeding stations was strongly urged by local governments. In 1914 when the National Institute began distributing the parent eggs of F_1 hybrids, local breeding stations had already been set up in 26 prefectures to receive them. It is therefore very important to stress, in connection with the rapid diffusion of F_1 hybrids, that the existence of the grass-roots movement to improve and standardize silkworm varieties in various prefectures greatly contributed to accelerating the diffusing speed of F_1 hybrids. It meant that a well-organized network for local diffusion had already been in part established before the nation-wide distribution of F_1 hybrids began.

B) The Superiority of F_1 Hybrids and Their Diffusion

1. The Commencement of Egg-distribution by Experimental Stations

Immediately after their establishment, the National Institute and its four branches started the work of the pure line separation, and scientifically confirmed, as early as 1913, the distinct superior qualities of F_1 hybrids by the variety tests on 48 different fixed and hybrid varieties. Of the F_1 hybrids examined, a Sino-Japanese hybrid, *Aojuku*-by-*Daientō*, was most famous for its excellent quality. Almost all F_1 hybrids proved to be superior to traditional varieties on a number of points: they required the shorter feeding periods; the percentage of larvae loss was smaller; and the cocoons had higher percentage of raw silk with easier reelability. These traits were also confirmed at about the same time by the Second Nagano Prefecture Silkworm-egg Breeding Station. The National Institute continued rigorous scientific testing of these qualities, publishing its final results on spring silkworms in 1917, and on summer-autumn worms in 1920, in its Bulletins.[15] They showed conclusively that the F_1 hybrid was much better than other indigenous fixed varieties in each major category of comparison: filament length; filament size; raw-silk percentage; missing larvae percentage; feeding period; double cocoon percentage; etc.

In 1914, when the name of the National Institute was changed to the National Sericulture Experimental Station, the first parent eggs for F_1 hybrids produced in the Station were distributed free of charge to local egg-breeding stations and training centers in all parts of Japan. In the first year, only 1,084 silk-moths of six varieties were distributed, with recommendations of twelve authorized combinations for crossing. But the significance of the distribution of the parent eggs for F_1 hybrids by government institutions was great for the development of the Japanese sericulture industry. The parent eggs were presumably passed on to private egg-producers *via* the local egg-breeding stations in 1915. Hence the first production of F_1 hybrids in Japan is considered to have been in the spring of 1916.

In 1915, when the distribution of mother moths for summer-autumn rearings was first made, the total number of moths transferred from the central station in the year increased greatly to 10,442. Thereafter, between 30,000 and 70,000 moths were distributed to the local stations on a continuous basis, facilitating the rapid diffusion of F_1 hybrid silkworms. The number of authorized combinations for hybridization of the moths obtained was substantially expanded as well. This reflected also in another aspect that the mother moths

[15] See *Sangyō shikenjyō hōkoku* [Bulletin of the National Sericulture Experimental Station], Vol. 2, No. 2 (1917), pp. 95–222 and also Vol. 5, No. 2 (1920), pp. 105–92.

distributed by the central station, which in 1915 accounted for only 1.7 percent of the moths produced independently by the prefectural egg-breeding stations, were increased to 44.2 percent in 1917 and 53.1 percent in 1918. That is, the former strains occupied the majority of distributed eggs to private producers as early as 1918.[16]

As is shown in Figure 1, the diffusion of the F_1 hybrid steadily progressed in various prefectures. However, despite its rapid success, the F_1 hybrid was not without problems. Two points must be mentioned. First, the method of producing F_1 hybrids was much more complicated and labor intensive than of the traditional fixed varieties. For instance, as the timing of eclosion of two parent pupas is in general not identical, it becomes necessary to accelerate or retard the emergence of one of the parent moths in order to match its timing. Moreover, to minimize unsuccessful copulations, it is essential to identify the sex of each pupa as accurately as possible, either by the weight method or by the pupa inspection method. Thus adequate technical knowledge and equipment were a first requisite for successful production of the F_1 hybrid by the rather complicated method of one-batch rearing. Besides, its production and rearing required a minimum scale sufficient to ensure suitable profits. Consequently smaller egg-producers who could not meet these two preconditions were gradually eliminated from the market during the diffusion process. The average size of egg-manufacturers in subsequent years expanded substantially as a result.

Secondly, the F_1 hybrid for summer-autumn rearing was not regarded as much more advantageous than the indigenous varieties, since it frequently produced poor crops at the initial stage of diffusion. In other words there was no decisively superior variety for summer-autumn rearing, as even the central station strains for summer-autumn F_1 hybrids had to undergo repeated and trial and error attempts at hybridization for some time. For instance, the crossing combinations designated by the National Sericulture Experimental Station were modified many times, and the number of combinations in use showed no sign of decreasing.

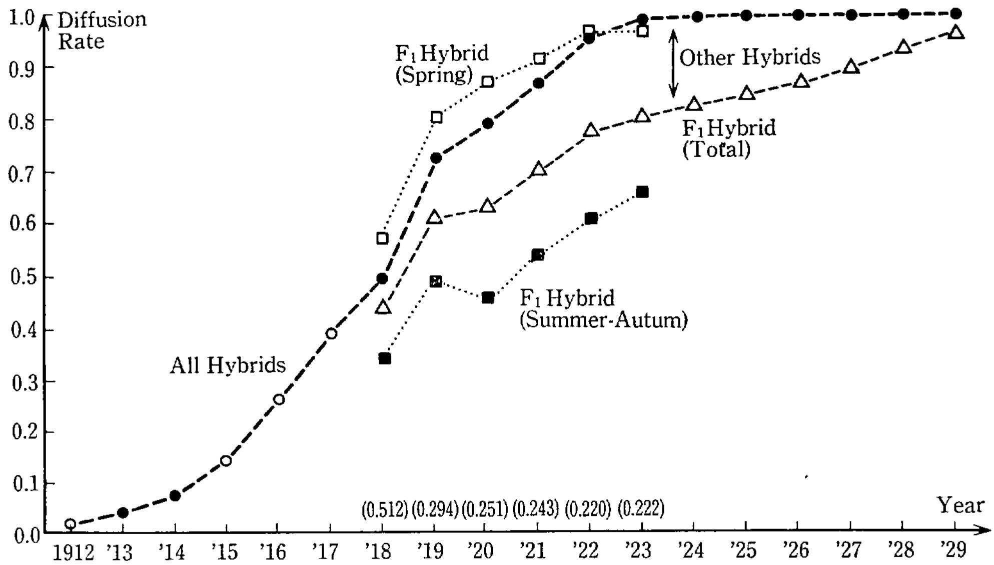
On the other hand the number of varieties prepared by prefectural egg-breeding stations reached a large figure.[17] Also traditional varieties adapted to the specific conditions in each region were generally preferred and encouraged. That is, for the summer-autumn rearings, indigenous fixed varieties belonging neither to nationally nor prefecturally developed strains continued to occupy a place of prominence in various sericulture regions.[18] Hence, Figure 1 shows that the diffusion rate for summer-autumn F_1 hybrids was appreciably lower than for spring F_1 hybrids. It was still only 66.7 percent in 1923, and the completion of diffusion was not achieved until around 1929. In other words the summer-autumn F_1 hybrid was

[16] Calculated from Nōrinshō, *Sanpinshu ni kansuru chōsa*. There existed two different kinds of silkworm-eggs distributed by the prefectural egg-breeding stations: the lines selected out by the National Sericulture Experimental Station; and the so-called local own silkworm-eggs developed on an independent basis by the egg-breeding stations in each prefecture.

[17] Whereas the number of national line varieties was between 20 and 30, the number of local ones was more than two hundred around 1916, although the latter gradually decreased. See Nōrinshō, *Sanpinshu ni kansuru chōsa*.

[18] In 1919, 31.3 percent of ordinary commercial eggs for spring rearing and 71.1 percent of those for summer-autumn rearing were produced from the parent eggs not belonging to either national or prefectural station-bred eggs (See *Sanpinshu ni kansuru chōsa*). They belonged to other strains independently developed by the private sector. Even as late as 1924, 19.0 percent of all commercial eggs still belonged to the third group (See Sanshi Dōgyōkumiai Chūōkai, *Sanshi tōkei nenkan, 1930* [Sericulture Statistical Yearbook, 1930]).

FIG. 1. PROGRESS IN DIFFUSION OF HYBRID VARIETIES



Notes: 1 The ○ of all hybrids stands for an estimate from the normal probability paper.
2 Figures in parentheses show the coefficient of variations.
Sources: *Sangyō torishimari seiseki*, 1912–17, *Sangyō torishimari jimu seiseki*, 1918–29, and *Sanshigyō ni kansuru sankō shiryō, Dai 3-ji.*

not broadly accepted as a stable and superior variety among various prefectures until the coming of an era of the artificial non-hibernating egg produced through artificial hatching techniques.

2. The Important Role of Big Silk Filatures in the Diffusion Process

The technical difficulties of producing F_1 hybrids were steadily overcome, as producers became better acquainted with cross-breeding techniques under the energetic guidance of the central and local experimental stations. Furthermore, behind the rapid development of F_1 hybrids existed the overwhelming superiority of the F_1 hybrid over other varieties, which by itself would have encouraged egg-producers to overcome the technical complexity of F_1 hybridization. As Figure 1 indicates, the rapid diffusion of F_1 hybrid silkworms dates from about 1919, and its rate in 1923 already accounts for 80.2 percent of all varieties reared. Particularly, in the case of spring F_1 hybrids, diffusion was almost completed by this year, with 97.8 percent of all spring rearing varieties being F_1 hybrids.

This high diffusion rate was partly due to the establishment of a network for distributing the parent eggs of F_1 hybrids, centering around the sericulture experimental stations at the central and prefectural levels. There is, however, another factor that helps explain the extremely rapid diffusion of F_1 hybrids, viz. the activity of the private egg-producers themselves. Since its creation in 1911, the National Station had scientifically proved step by step the superiority of F_1 hybrids, and the rearing of the hybrid came to be encouraged as a matter of policy. As this shift occurred, many egg-card manufacturers and progressive sericulture farmers took greater interest in hybrids and foreign races, and they became increasingly active in developing the hybrids and improving the existing varieties by their own hands.

Although information on hybrids prior to 1918 is limited, the basic trend in hybridization is confirmable from the qualitative data derived from variety lists for various parts of Japan.[19] In 1912, for instance, only twelve varieties out of 867 (1.4 percent) are listed as "crossed" or "hybrid," but 129 out of 958 varieties (13.5 percent) bear the designation in 1914. In 1916, when the first national station bred strains had appeared, as many as 971 out of 3,317 varieties (29.3 percent) are recorded as hybrids. The increase in the number of hybrids does not necessarily straightforwardly signify an exactly corresponding increase in the quantity of hybrid silkworms diffused, but it does indicate a steady trend in this direction. Since it can be roughly confirmed from the same data that, among the ten principal varieties in each prefecture, the proportion of silkworm-eggs bearing the name "crossed" or "hybrid" was steadily increasing.

Undoubtedly not a small portion of these "hybrids" cannot be regarded as genuine F_1 hybrids in the strict sense of the term, but it is worth while to remark that a fair number of the varieties were distinctly marked as being F_1 hybrids, or were verifiable as such from supplementary information. It is also noteworthy that the rapid growth in the number of varieties reared was paralleled by a rise in the number of "improved" varieties, which was an indicator of the producers' desire to develop better silkworms. Meanwhile the rearing of foreign races for hybridization gradually increased as well, particularly in the early 1910's. For instance, hybrids with foreign varieties already accounted for 4.4 percent in 1913, and 7.1 percent in 1914, most of these being spring reared silkworms from Sino-Japanese hybrids.[20]

It should be sufficiently emphasized that private egg-producers had already on their own initiative laid the groundwork which enabled them to adjust and absorb technical innovations in cross-breeding under the new system, before the diffusion of F_1 hybrids through the distribution network organized around the sericulture experimental stations started. Consequently, when the parent eggs of F_1 hybrids became available, a rather well-organized infrastructure was ready and waiting to receive them. This is also confirmed by the fact that as many as 35.6 percent of all eggs were still being produced independently of the national and local experimental stations even in 1929, when the diffusion of F_1 hybrids was almost completed.[21] In other words it attests to the active entrepreneurship of private egg-manufacturers who persisted in their tireless efforts to improve varieties. Among them, the big reeling filatures played a leading role in promoting the diffusion of F_1 hybrids by most quickly recognizing the advantages of heterosis. It was they who strongly urged the standardization of silkworm varieties, since they were expected to gain most from the prevalence of F_1 hybrids.

[19] The Sericulture Industry Law, however, was revised in 1917, and a notification system was set up. This implies that, after 1917, we cannot distinguish "crossed" or "hybrid" varieties from ordinary fixed varieties by their names, since they were no longer required to be named as such.

[20] Nōrinshō, *Nōmu ihō dai 56-gō: Sanshigyō ni kansuru sankō shiryō, dai 3-ji* [Agricultural Bureau Report No. 56: Reference Materials on the Sericulture Industry, the Third], 1916. The Diffusion rate was derived by adding the cards of both ordinary (commercial) and special (parent) silkworm-eggs produced in each prefecture. 100 moths are counted as one card.

[21] Calculated from *Sanshi tōkei nenkan, 1930.*

One of these well-known filatures, the Katakura Silk Co. in Nagano, was quick to seize upon the new development, and in 1914 organized the All Japan Association for the Propagation of F_1 Hybrids. Actively engaging in the production and diffusion of these hybrids, Katakura became their most energetic advocate. More specifically speaking, as early as 1914 the Katakura Silk Co. experimentally distributed 1,088 F_1 hybrid egg-cards to sericulture farmers located nearby in Nagano Prefecture.[22] Based upon the success of this initial venture, the Company set up its own subsidiary and started the mass-production of F_1 hybrds. That is, their parent eggs of European semi-fixed races were reproduced by themselves, instead of obtaining from the government experimental stations. In 1915 Katakura distributed 63,000 egg-cards to sericulture farmers in 40 prefectures *via* their own branch-filatures in the respective regions. The Company continued thereafter to steadily expand its activities, launching full-scale into the production and diffusion of F_1 hybrid silkworms.

Two important observations must be pointed out here concerning the diffusion process itself. First, the conventional negative image of hybrids held by many sericultural farmers was wiped out by the energetic efforts of the Company. To realize it, educational sessions were organized in the major cocoon purchasing regions, instruction manuals for F_1 hybrid rearing were distributed to the farmers, and professional guidance in the earlier phases of silkworm rearing was provided by the Company's itinerant experts. This technical instruction and educational activity provided by the Katakura Co. was the principal reason for the very rapid diffusion of F_1 hybrids and for the conversion of sericulture farmers who had formerly been stubbornly attached to traditional fixed varieties into adopting the new hybrid variety. Secondly, Katakura first introduced a kind of guarantee system whereby the company agreed to purchase back mature cocoons after rearing. It was called *Tokuyaku torihiki* [special subcontract transactions] and was highly instrumental in reducing the risk felt by sericulture farmers in rearing F_1 hybrids.[23] This system gradually spread over all parts of the country and played a central role in assuring silk-reeling filatures of high quality F_1 hybrid cocoons. On the other hand, however, this consignment system always reflected the power relation between farmers and filatures, and began to be used in the 1930's by the latter to exploit the former.

It was easily to be expected that other reeling filatures besides Katakura would also start to take an active hand in promoting the introduction of F_1 hybrids. For instance, the Gunze Silk Co., which had previously consigned the production of eggs to its subsidiary, Taiseikan, began to develop new varieties by setting up a new larger egg-producing department in 1915. It developed a unique network (*Bunjō kumiai*) of subcontracted farmers who

[22] The parent eggs used to produce the F_1 hybrids were *Nihon-nishiki, Ascoli, Szekzard, China No. 7* and *Blanc Pure*. *Honpō ni okeru ichidaikōzatsu sanshu hasshō-shi,* however, does not provide and further detailed information on the production of those parent eggs. Judging from the fact that *Sanpinshu ni kansuru chōsa* did not list those parent eggs as strains distributed in 1914 by the central or local egg-breeding stations, it is quite plausible that the Katakura Co. itself produced them with the cooperation of the Second Nagano Prefecture Silkworm-egg Breeding Station and/or the Matsumoto branch of the National Institute of Silkworm-egg Production.

[23] As regards the origin of special subcontract transactions, the names of the Muroyama, San'in and Gunze Cos. should also be mentioned, since they had earlier adopted a similar guarantee system. After around the turn of the century, they introduced the systems of credit transactions and conditioned weight transactions, which took the form of subcontracted rearing and price agreements based upon an objective appraisal of quality. In the case of the Katakura Co., the special subcontract system spread from Saga to other prefectures, where county agricultural associations and sericulture cooperatives had prepared the groundwork.

produced the designated parent eggs. At about the same time, several other big filatures as well entered the egg-production industry, including the Ayabe Silk of Kyoto in 1917, Kansai Silk in Mie (1917), Nippon Silk of Tottori (1918), Higo Silk in Kumamoto (1913), etc. These combined filatures of reeling and egg-production produced silkworm eggs on a considerably larger scale than of the average egg manufacturer, as is typically shown in the cases of the Katakura and Gunze Silk Cos. Within several years they rapidly developed and began to influence the developmental trend of the silkworm-egg production industry as a whole.

This tendency is distinctly confirmable, for instance, from the special survey conducted by the Ministry of Agriculture and Commerce in 1922.[24] 18 silk-reeling filatures were then engaged in the combined production of egg-cards, and produced about 21.5 million silkmoths in the year. That is, they consisted of 740 thousand moths for parent egg production and 20.8 million moths for commercial egg production, accounting for 13.0 percent and 13.8 percent of the total moths in their respective production categories in Japan. It should be also pointed out that most of these eggs stood comparison in quality with the silkworm eggs produced by the sericulture experimental stations,[25] and were said to be relatively easier to rear. This was because, in order to produce quality cocoons, the farmers' rearing process from incubation to cocoon-spinning was strictly controlled by the filatures' administrations, based upon their long experience of improving varieties and also the special subcontract system.

III. *Factors Promoting the Rapid Diffusion of F_1 Hybrids*

A) A Statistical Understanding by Probit Analysis

1. Variables and an Estimated Result

In Section II, we had confirmed from aggregate data a fact of the extremely rapid diffusion of F_1 hybrids and the basic characteristics of the diffusion process. It was also mentioned, as supporting evidences for the basis of rapid diffusion, that: (1) the strong grass-roots tradition for private egg-producers to improve silkworm varieties on their own initiative; (2) the quick establishment of a diffusion network centering on the national and prefectural sericulture experimental stations; and (3) the swift adoptions of F_1 hybrids by leading silk-filatures and their promoting activities to realize the rapid diffusion. However, a more rigorous and thorough-going analysis taking into account the direct factors behind

[24] See *Sanshu seizō o nasu kaisha, kumiai sonotano dantai ni kansuru chōsa* [Survey on Companies, Co-operatives and Other Groups Engaged in the Production of Silkworm-eggs], Nōshōmushō, 1923.

[25] The parent eggs produced by the National Station were considered to be highly superior because of its strict pure line separation. But it should be pointed out that, as these eggs were isolated and produced from traditional fixed varieties, they naturally had some links with the latter. For instance, *National Japanese No. 1* was from the *Akajuku* line, and *No. 2* from the *Daisei* line. Similarly *National Chinese Nos. 1* and *2* were of the *Seikei* and *Keien* lines respectively. *Blanc Pure* and *Szekzard*, which were mainly reared by the Katakura Co., corresponded to *National European Nos. 3 and 6* respectively. For more details, see H. Hiratsuka (ed.), *Kindai sanpinshu ikushu kiroku* [Breeding Records on Modern Silkworm Varieties], Sanshi Kagaku Research Institute, 1961, and T. Yokoyama, "Sanshi gijutsu no hattatsu-shi (10)," *Sanshi kagaku to gijutsu* [Agricultural Science and Technology], August 1965.

the introduction of new varieties as well as the above-mentioned institutional aspects, is preferable to determine more exactly the factors contributing to the diffusion of the F_1 hybrid.

For this purpose, probit analysis shall be applied to prefecture-wise data for 1918 when the diffusion of F_1 hybrids was still in a relatively early phase. More specifically, there exist two reasons for the selection of the year 1918. First, it is the first year in which *Sangyō torishimari jimuseiseki* provided detailed information on F_1 hybrids by prefectures. The second reason is that it is the most appropriate year for identifying the main factors determining different diffusion rates among prefectures, as is suggested by the values of the coefficient of variation in Figure 1, which sharply decline after 1919.

Again there exist two reasons for using probit analysis, notwithstanding the fact that the estimates it produces are not much different from those of simple linear regression analysis. The first is that, although the available data on F_1 hybrids consist of aggregate information by prefectures, each egg-producer was making the binary decision whether or not to introduce the F_1 hybrid beneath the aggregation. Hence the data could more reasonably be interpreted as the collection of such binary decisions for each prefecture. Besides, the prefecture as an administrative unit might have positively justifiable significance for sericulture technology, since diffusion activities were closely related to prefectural activities, such as the self-supply policy of silkworm eggs within a prefecture, the existence of sericulture experimental stations as information centers, the Government's sericulture subsidies, the network of trade associations, agro-sericultural education, etc.

Secondly, the decision-making whether or not to introduce F_1 hybrids is supposed to be normally distributed around some critical value, which can be expressed as an integrated index of the different motives promoting diffusion. In other words, when the diffusion phenomenon is grasped as the accumulation of such patterns of response to the overall effect of different factors, it is expected to have the well-known S-shaped growth curve. Consequently far better fit should be achieved with a non-linear, normal c.d.f. curve than with a linear regression line. In addition the result so obtained will be comparable with our previous analysis of the diffusion of the multi-end reeling machine, where probit analysis was applied as well for similar reasons.[26] The comparison may contrast a sharp distinction between the diffusions of manufacturing and agricultural technologies.

In our statistical analysis, the following 8 variables shall be examined to determine the factors promoting the diffusion of F_1 hybrids. The first two variables are related to the technological level of egg-production. They are the average volume of egg-production by prefectures [x_1] and the self-sufficiency rate for silkworm eggs in each prefecture [x_2].[27] The former is regarded as an indicator of the modernization of silkworm-egg manufacturers, and the latter is considered as a measure of the degree of advance in egg-breeding technology, since egg-exporting prefectures must have possessed superior technology to egg-importing prefectures. For these variables, the quantity produced should be naturally adopted the preceding year's. The third variable introduced is the proportion of special subcontract

[26] Concerning the significance of the prefectural unit in the diffusion process, the reader is referred to the author's paper, "Silk-reeling Technology." For details on probit analysis, any standard textbook of statistics with special reference to medical science may be consulted. It is not explained here to save space.

[27] The average size is the number of egg-cards divided by the number of egg-producers. The self-sufficiency rate is egg-cards produced minus egg-cards reared within a prefecture divided by the latter.

transactions by prefectures [x_3],[28] which can be regarded as a proxy variable to measure the influence of reeling filatures over sericulture farmers. Because of data unavailability, the figures are substituted by the data of 1928, the first year for which information became available. However, this expedient appears to be adequate for our immediate purpose.

The next group of variables is concerned with educational and R&D activities related to sericulture technology. These are the expenditure on sericultural technicians [x_4] and the sericultural education intensity [x_5]. The former is a flow variable giving expenditure on technicians as a proportion of overall sericulture-related expenditure in the local government budget, whereas the latter is a stock variable giving the accumulated number of sericulture school graduates deflated by the total area of mulberry fields in each prefecture.[29] One dummy variable is introduced to measure the progress of the institutional network for the diffusion of F_1 hybrids. It can be regarded as a kind of index for the earlier start of parent-egg's distribution [x_6]. It is a binary variable depending upon whether or not the proportion of parent eggs distributed by the local experimental station is more than 20 percent at the time of the commencement of the distribution of F_1 hybrids by the national sericulture experimental station in 1914. The final group of variables is related to the background conditions for the sericulture industry in general in each prefecture. They are the proportion of summer-autumn rearings [x_7] and the proportion of sericulture-related expenditure in the total prefectural subsidies for industrial promotion [x_8]. The former reflects the relationship between the sericulture industry and other agricultural activities, whereas the latter expresses its relationship to other industrial activities in general.[30]

Using these eight variables, the probit analysis provides the following estimate by the iterative maximum likelihood estimation method,[31] viz.

$$\hat{y} = \Phi(\hat{\beta}'\mathrm{X}) \qquad \Phi\text{: c.d.f. of N(0,1)}$$

$$\begin{aligned}\hat{\beta}'\mathrm{X} \equiv 5.097 &+ \underset{(1.38)^{*}}{0.121x_1} - \underset{(-1.31)^{*}}{0.107x_2} + \underset{(2.88)^{***}}{0.220x_3} + \underset{(2.00)^{**}}{0.134x_4} \\ &+ \underset{(2.67)^{***}}{0.209x_5} + \underset{(1.46)^{*}}{0.107x_6} + \underset{(1.96)^{**}}{0.139x_7} - \underset{(-1.63)^{*}}{0.115x_8}, \qquad \cdots\cdots\cdots(1)\end{aligned}$$

$\chi^2 = 3.807$; d.f. being 37; figures in parentheses being asymptotic t-values; *, ** and *** denoting the significance at 10 percent, 5 percent and 2.5 percent level (one-sided) respectively.

[28] The rate of special subcontract transactions is measured in terms of cocoons as the amount of cocoons reared under the subcontracting system divided by the total production of cocoons in each prefecture.

[29] The total number of graduates majoring in sericulture-science is obtained as the accumulated number of them up to 1914 plus the enrolled number in the subsequent years up to 1918 from the sources cited on Footnote 30.

[30] The sources of statistical data for the above eight variables are given as follows: *Sanshi tōkei nenkan, 1930* and Nōshōmushō, *Sanshigyō ni kansuru dōchōfuken no shisetsu gaiyō, 1918* [Summary of Sericultural Institutions and Their Expenditure in Prefecture, 1918] for x_3 and x_4, *Sanpinshu ni kansuru chōsa, 1920* for x_6, *Sanshigyō ni kansuru sankō shiryō, dai 3-ji, Sanshigyō ni kansuru dōchōfuken no shisetsu gaiyō, 1918* and Nōshōmushō, *Nōshōmu tōkei hyō, dai 35-ji* [Statistical Yearbook on Agriculture and Commerce, the 35th] for x_5. For the other four variables x_1, x_2, x_7 and x_8, all the data are adapted from *Nōshōmu tōkei hyō* (the 34th and 35th).

[31] For reference, the estimate by regression analysis is given as follows:

$$y = 0.534 + \underset{(1.34)}{0.042x_1} - \underset{(-1.41)}{0.041x_2} + \underset{(2.94)}{0.079x_3} + \underset{(2.11)}{0.051x_4} + \underset{(2.76)}{0.070x_5} + \underset{(1.57)}{0.041x_6} + \underset{(2.22)}{0.056x_7} - \underset{(-1.76)}{0.045x_8}$$

$R^{*2} = 0.486$

The reliability of this estimate of the equation (1) as a whole is sufficiently shown by the distinctly low value of χ^2 (cf. χ^2_{37} (0.995) = 18.59). Furthermore all coefficients in the equation (1) are thoroughly significant at the 10 percent level as is shown by the asymptotic *t*-values. It is to be noted that, as all variables are standardized, direct comparisons between the sizes of each variable's coefficient are possible.

2. An Interpretation of the Result and the Diffusion Patterns

The findings resulting from the estimate (1) can be set out here. First, among the eight variables, the proportion of subcontract transactions for cocoons [x_3] is observed to have the greatest impact on the promotion of the diffusion of F_1 hybrids. As is noted above, however, its effect might be considered to be discounted to some extent, since the data for this variable are adapted from a later period. But our approximation can be justified in the twofold senses that, despite different absolute levels, the relative effect is virtually the same because of standardization of variables, so long as the relative position of each prefecture was not changed, and that the data of 1928 are not necessarily overevaluated, when the subcontract transaction is broadly defined to include its prototypes, viz. consignment productions and advance subcontracts. As was observed in the case of silk-reeling technology, the great importance of the pioneering role of the big silk filatures should be stressed again also in the diffusion of F_1 hybrid egg-production technology.

Next to the special subcontract variable, the second greatest contribution to the spread of F_1 hybrids arises from the variables related to education and R&D, viz. the sericultural education intensity [x_5] and the expenditure on technical experts [x_4]. That is to say, the more actively a prefecture invested in sericultural education and R&D, the more quickly it introduced and diffused the improved varieties. Since such prefectures, with their newly accumulated knowledge of sericultural science and technology, were better able to appreciate the superiority of F_1 hybrids. In regard to the data on educational activities, the total number of sericultural graduates includes those from training centers & courses and also professional sericultural schools. Many of these graduates contributed in numerous ways to the development and diffusion of new technology at the local level as sericultural instructors or technical experts in trade associations, local governments, etc. The number of graduates stands approximately in proportion to the number of sericultural instructors, data on whom became available after the widespread introduction of the license system for instructors.[32] With respect to the data on R&D activities, the expenditure on technical experts includes not only the various expenses for sericultural specialists working in the silk control centers and egg-breeding stations but also the share of technician-related costs in the silk industry promotion funds (hence including subsidies to agricultural and trade associations as well). Accordingly one may safely conclude that this expenditure reflects accurately enough the general attitude towards technical orientation and improvements at the local level, as well as the fruits of them.

The third factor dominating the diffusion of F_1 hybrids is the environmental conditions represented by the proxy variable of the proportion of summer-autumn rearings [x_7]. The higher this ratio in a given prefecture, the higher the rate of F_1 hybrid diffusion. Since a

[32] The number of sericulture instructors was without doubt smaller than that of graduates who had studied sericulture science. But the relative distribution of the two among prefectures was quite similar with each other. See *Yōzan ni kansuru chōsa* [Survey of the Sericulture Industry], Nōrinshō, 1927.

high ratio of summer-autumn rearings implied greater importance for the sericulture industry relative to other agricultural activities, and also greater development of the cash-crop oriented regional market. Consequently those prefectures with the high ratios were active in introducing new technology and improved varieties. In the case of the sericulture-related subsidy ratio [x_8], another proxy variable for environmental conditions, the contribution is relatively smaller. Significant, however, is the fact that the lower the proportion of sericulture-related expenditures in total industrial promotion subsidies (i.e. the higher the relative expenditures on manufacturing, commerce, etc.), the higher the diffusion rate of F_1 hybrids. As in the case of summer-autumn rearings, this variable also could be interpreted as expressing the implicit relationship between the development of the market and the diffusing speed of new technologies.

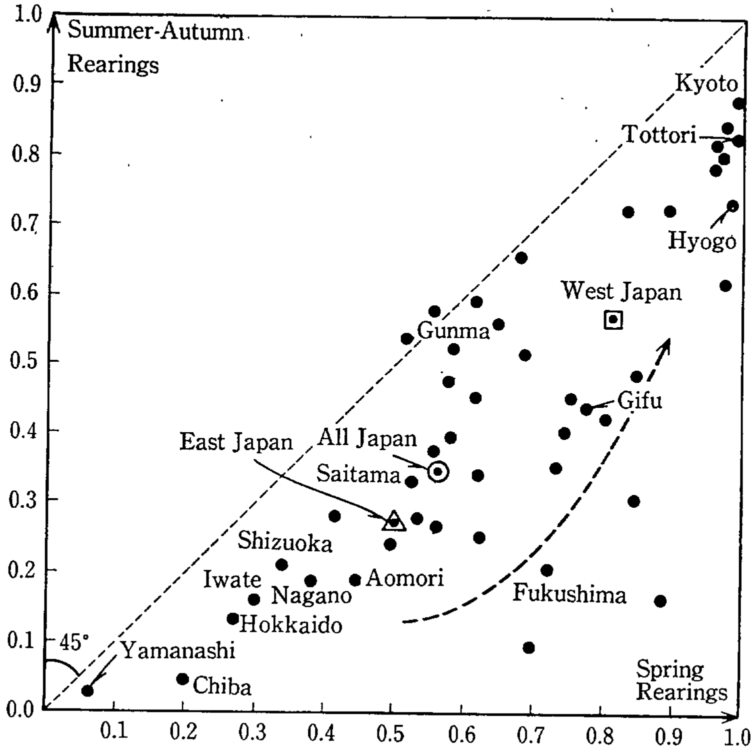
Fourthly, the role of the earlier start index for parent-egg distribution [x_6] proves to be less important than we had anticipated. Two factors may be adduced to account for this: first, prefectural egg-production stations were able to set up distribution systems rather easily; and second, private egg-producers excluded from the index in fact played a fairly important role in the establishment of those systems. Similarly it is difficult to maintain that the variables related to egg-producing technology [x_1, x_2] have exerted sufficient influence on the diffusion of F_1 hybrids, when judged from their t-values and the size of the coefficients. Although we find the expected correlation between the average scale of egg-production and the rate of diffusion, it is puzzling to find that the more involved a prefecture was in exporting egg cards, the lower its rate of diffusion of F_1 hybrids. This rather peculiar finding is considered to be basically originated from the big differences in diffusion rates between East and West Japan.[33] More specifically, if one checks the in- and out-flows of silkworm-eggs by prefectures in each region, then the egg-exporting prefectures are generally found to have higher diffusion rates than egg-importing prefectures. This trade was normally restricted to fairly short distances within neighboring prefectures, and hence, the diffusion rates in importing prefectures in the East were not necessarily higher than those in exporting prefectures in the West, as the result reflecting the large discrepancy between the rates of diffusion in the East and the West. It was therefore difficult to draw a clear-cut conclusion for the aggregate level of the whole of Japan.[34]

Notwithstanding, the price of silkworm-eggs and cocoons and the wages of sericulture workers are generally thought to have had some influence on the diffusing speed of new varieties, price-related variables were excluded from our analysis. This is because the price of a given variety was roughly the same throughout the country, although quality differences between varieties were reflected in differences in price. With regard to wages, national data are unavailable, and the fragmentary information on them affirms almost no regional variation. These considerations preclude the possibility of introducing these variables. Furthermore, one might conceivably substitute some other variables for those already chosen, say, the productivity of rice production or the planted area of mulberry trees instead of the proportion of summer-autumn rearings, or the production of raw silk instead of the proportion

[33] As in our previous analysis for the multi-end reeling machine, East and West Japan are composed of Hokkaidō, Tōhoku, Kantō and Chūbu regions, and of Kinki, Chūgoku, Shikoku and Kyūshū regions respectively.

[34] For more details on the silkworm-egg trade in each prefecture, see, for example, *Yōzan ni kansuru chōsa*, N. Hayakawa, *Sanshigyō keizai kōwa* [Lecture on the Sericulture Economy], 1923, etc.

FIG. 2. RATE OF DIFFUSION OF THE F_1 HYBRID IN 1918
(Spring *vs.* Summer-Autumn Rearings)



Source: Sangyō torishimari jimu seiseki, 1918.

of special subcontract transactions for cocoons, etc. None of those substitutes, however, proved on examination to be statistically significant, and only the variables with high levels of significance have been retained after the so-called forward selection of variables. The influence of trade and industrial associations on the diffusion also failed to qualify statistically and was therefore not included in the regression equation.

In order to understand the above statistical analysis in the context of the geographical background, a few important characteristics of the relative positions of prefectures should be pointed out from Figure 2. First, as was previously mentioned, the introduction of F_1 hybrids in each prefecture almost always started with the spring rearing, and then gradually diffused to the summer-autumn rearings. Moreover the adoption rate of F_1 hybrids in the summer-autumn rearings generally accelerated as that in the spring rearings increased. Secondly, there exists a distinct gap between the diffusion rates of East and West Japan (the weighted average rates being 37.1 percent and 66.7 percent respectively). For instance, major sericulture prefectures in East Japan, such as Yamanashi (4.0 percent), Chiba (10.8 percent), Shizuoka (26.0 percent), Nagano (28.5 percent), recorded very low rates of diffusion, whereas extremely high values were achieved in the main rising-prefectures of the West, such as Kyoto (93.3 percent), Tottori (89.5 percent), Hyōgo (86.6 percent), etc. That is, the diffusion of F_1 hybrids in the latter prefectures was almost completed as early as 1918, in contrast to the late start of the former. The factors promoting diffusion have been extracted in our statistical analysis. Thirdly, the so-called traditional sericulture regions (*Ko-sanchi*: Gunma, Saitama and Fukushima) displayed higher rates of diffusion than the so-called late-comer regions (*Shin-sanchi*: Nagano, Gifu and Yamanashi) in East Japan.[35] This would seem to indicate that the traditional areas, outstripped by the spectacular growth of sericulture in the late-comer regions during the Meiji period, had by this time retaken the lead in improving existing technology and adopting new methods. An exactly similar phenomenon was observed in the case of the multi-end reeling machines. These experiences of the shift of leading centers as to some specific technological innovations appear to suggest us a "seesaw phenomenon" hypothesis on the relationship between the diffusion of new technology and the inter-regional competition.

B) Organizing Diffusion Activities and the Demand Factor

1. Technical Education and R & D Activities

So far in our probit analysis we have confirmed that the most important factors promoting the diffusion of F_1 hybrids were the initiatives of large silk-reeling filatures and the educational and R&D activities associated with their introduction. These two factors shall be discussed in this section more concretely against the historical background.

It was the educational and R&D activities that promoted the transition from the age of "silkworm-egg dealers' technology" to the age of "experimental station technology," and that realized the rapid diffusion of F_1 hybrids by consolidating the foundation for accepting the new technology. With the enactment of the Professional School Law in 1903, the Meiji government also started to make an effort to establish a network of industrial schools and vacational training centers. In the field of sericulture science as well, the higher education system and the industrial schools were rapidly expanded within a short period of time between the late Meiji and early Taishō. For instance, in 1910 Ueda Sericulture Professional School was established, in 1914 Sericulture Research and Training Centers in Tokyo and Kyoto were converted into Sericulture Colleges, the sericulture science section was opened at Kyūshū Imperial University and so forth. On the other hand intermediate level institutions, such as agro-sericulture schools or sericulture training centers, provided the practical and scientific knowledge of sericulture technology which was indispensable for the widespread diffusion of new varieties over various prefectures. There is no doubt that the system of higher professional education was crucial in promoting advanced research on the genetics, hatching, incubation, etc. of silkworm and in transforming those findings into practical and profitable improvements. No one, however, can deny that the promotional and educational activities of the general sericultural education system rendered the diffusion of the various improvements all the more effective.

According to the *Nōrin gyōsei-shi* [Administrative History of Agriculture and Forestry],

[35] The diffusion rate for F_1 hybrids in the traditional sericulture regions was 48.7 percent (spring rearings 61.9 percent and summer-autumn rearings 32.8 percent), whereas the late developing regions recorded only 30.0 percent (spring rearings 40.6 percent and summer-autumn rearings 23.9 percent), when calculated from *Sangyō torishimari jimu seiseki, 1918.*

as of 1919 there were 145 public schools offering more than six months' education in sericulture science (53 national and prefectural institutions, 72 county schools and 20 schools by municipal school associations [*Gakkō kumiai*]). By 1924, five years later, this number had grown to 231, of which 194 were national and prefectural institutions and 37 belonged to school associations. Meanwhile intensive training was also given at prefectural egg-breeding stations in order to turn out a large number of sericultural experts.[36] *Sanshi yōkan* [Sericulture Handbook] provides a description of leading sericultural institutions, which suggests the importance of the agro-sericulture schools founded by municipal school associations and other organizations. By 1923, as many as 25,731 sericultural graduates, or 17 percent of the total 151,386, were from agro-sericulture schools set up, outside the national and prefectural system, by various associations (viz. school, trade and agriculture associations), companies, private individuals, etc.[37] More than half of those graduates (15,769) graduated from the schools organized and run by municipal school associations. It is certainly difficult to underestimate the tremendous significance of research and educational activities sponsored by the public educational system at the central level, but the role played by research and education in the development of the Japanese sericulture industry cannot be properly understood without reference to the dynamism resulting from the locally-based educational system set up by municipal, trade and agricultural associations, and other private organizations.

There is little doubt that the comprehensive educational efforts made to diffuse new sericultural knowledge and techniques were a major factor encouraging the rapid diffusions of F_1 hybrids. As was pointed out earlier, this resulted from the simple fact that a sizeable proportion of sericultural graduates found work locally as instructors or technicians in trade and agricultural associations, or took jobs connected with the sericultural industry in some way. In doing so, they made outstanding contributions to the improvement and diffusion of sericulture technology, about which they had obtained knowledge at their schools.[38] On another front the products of pioneering research on silkworm-eggs, raw-silk, mulberry trees, silkworm genetics and pathology began to be published in rapid succession after the end of the 19th century.[39] They were precisely the fruit of the earlier establishment of the higher educational system for sericultural science, as is shown in the typical example of the College of Agricultural Science, Tokyo Imperial University. Much of this research was of international caliber, and compared favorably with similar work conducted in France and Italy in those days. It should also be noted as a point of historical importance that such efforts were not confined to a handful of college academics; many first-rate studies were carried out at local egg-breeding centers and agriculture experimental stations as well. To describe all this research is beyond the scope of this paper, but at least two epoch-making innovations

[36] See *Nōrin gyōsei-shi*, pp. 921–22. Most of the county schools were transferred to the control of prefectures after 1919.

[37] See *Sanshi yōkan* and *Yōzan ni kansuru chōsa*. The contribution of local schools at the initial stage was remarkable. It is also to be noted that 68 percent of all sericultural graduates had studied sericulture science for more than 3 years. This attests to the high standard of sericulture instructors and technicians in Japan.

[38] The number of sericulture instructors amounted to 10,430 in 1925, 80 percent of whom were seasonal itinerant advisers. Later, as the special subcontract practice spread, the number of technical experts employed in silk filatures grew rapidly. See *Yōzan ni kansuru chōsa*.

[39] For more details, see *Nihon sanshigyō-shi*, Vol. 5 (History of Researches on Sericulture Science). A brief history of sericultural research is also found in T. Yokoyama, "Sanshi gijutsu no hattatsu-shi: (6), (7) and (8)," *Sanshi kagaku to gijutsu*, April, May and July 1965, respectively.

which definitely accelerated the diffusion of F_1 hybrids should be mentioned here. They are the development of new techniques for artificial hatching and sex-identification.

As is well known, artificial hatching is the practice of artificially giving a stimulus by some means to hibernating eggs, causing them to hatch without overwintering. Various principles of stimulating eggs were known theoretically from an early date; the brushing method, acid treatment, the electric pressure method, oxygen treatment, etc. were typical examples. Among them the only method to be developed on a practical basis was the hydrochloric acid treatment. In 1914, this technique was first practically applied by K. Koike with the aid of the warm-water permeance method, and it was later perfected in 1917 as the acid treatment after cold-storage method by T. Araki and E. Miura. The rapid diffusion of this new technique started around 1919 from Aichi Prefecture to the whole country. That is, the artificial non-hibernating eggs of summer-autumn rearings were still only 6 percent in 1921, but by 1926, five years later, the proportion had grown to 72.4 percent.[40] The development of artificial hatching techniques was of great importance for the diffusion of F_1 hybrids, especially for summer-autumn silkworms. Since they had been required the better management and more strict control of silkworm-eggs in the early phases of rearing, and the artificial rendered them possible.

Another improvement promoting the rapid diffusion of F_1 hybrids was the new technique of sex-identification. As early as 1904, S. Ishiwata, a classmate of Toyama's at the College of Agricultural Science, had already laid the theoretical basis for sex-identification through his research on the silkworm genital gland, known as the Ishiwata gland. In 1921 S. Karasawa developed from this research a practical sexing method which would be applied to mature larva, and also trained many specialists in his technique. This mature-larva-sexing method, which was a much easier and surer method than the weight method or the pupa-sexing method, began to diffuse quite rapidly from Nagano Prefecture throughout Japan. To produce F_1 hybrids efficiently, sex-identification of parent silkworms was essential and the completion of this surer method contributed greatly to promoting the diffusion of F_1 hybrids. It should be noted that these two major improvement, artificial hatching and sex-identification, were both developed by and diffused from local silkworm-egg breeding stations.

Similarly, in other fields of sericulture technology, pioneering research and its application to practical improvements were actively conducted by various educational and R&D institutions in different places. The innovations derived from such work were immediately introduced into production processes by the producers, i.e. egg-manufacturers and sericulture farmers, as soon as the profitability of new techniques became apparent. There seemed to be two major routes through which information concerning innovations was conveyed from scientists and technicians to the actual producers. The first well-organized channel was the institutionalized route that began with the egg-breeding stations and sericultural control centers, and proceeded to the sericulture department of the prefectural and municipal governments. From there, the information was usually passed to the local trade and agricultural associations from which progressive manufacturers and veteran farmers could easily access to it through their own networks. This was almost certainly the main path by which technological information travelled.

[40] Calculared from *Yōzan ni kansuru chōsa*.

The second channel was the route *via* sericulture graduates from various institutions in different localities, who obtained new information on sericulture technology through professional journals, manuals or lecture-notes and, after adapting it to fit local conditions and needs, guided actual producers to introduce them. Such cases are observable on a fairly broad scale, for instance, in the "Questions & Answers," and "Advice" columns or in the practical suggestions by technical experts of local egg-breeding stations appearing in the Journals of the Sericulture Industry and of the All Japan Raw Silk Association. It is not too much to say that the effectiveness of both channels of information in the long run was essentially dependent upon the education for sericulture technology and the development level of the market.

The strong influence of the second route on the diffusion of technology is demonstrated by the fact that the timing of practical publications on topics in sericulture technology faithfully reflected the demand for technology then being introduced. In the case of the F_1 hybrid technology, practical and introductory books about hybridization began to be published successively after 1914 by well-established publishing houses such as the Meibun-dō, Maruyama-sha, etc. For instance, as many as 13 titles on F_1 hybrid production were put into print in the single year 1917.[41] It should be kept in mind that these publications were published not only by a handful of leading publishers but also by local printers, egg-manufacturers, prefectural egg-breeding stations and trade associations.[42] Publications on F_1 hybrid technology ceased to appear around 1921, and titles concerning artificial hatching techniques thereafter came instead to occupy the place of prominence. This fact seems indirectly to support our previous conjecture that the diffusion of F_1 hybrids must have been almost completed by about 1923.

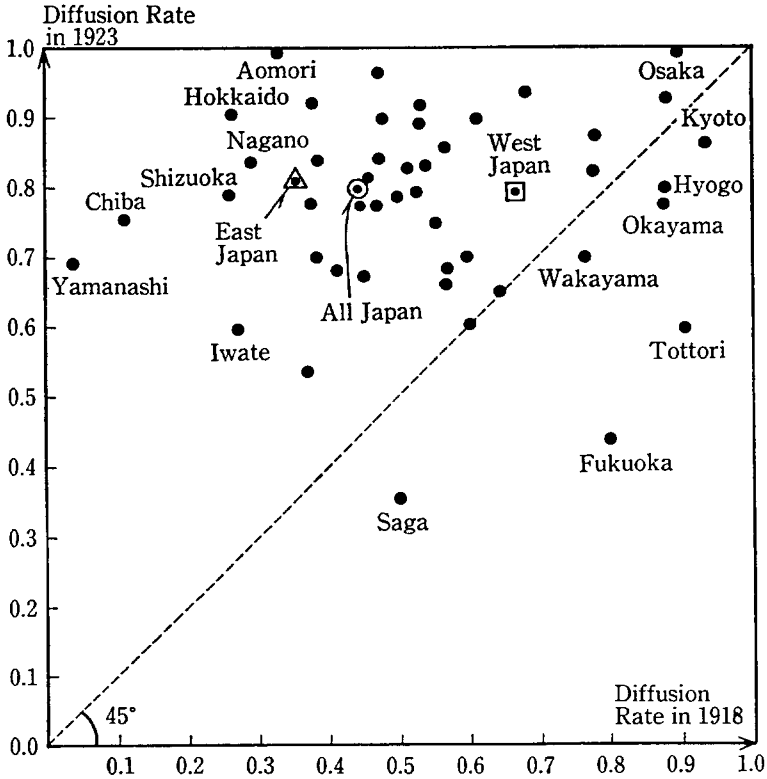
2. Raw Silk Demand as an Accelerating Factor

As the result of the sericultural education and R&D activities described so far, the diffusion of F_1 hybrids progressed very rapidly between 1918 and 1923, as is shown in Figure 3 which gives the movement for each prefecture. The most salient feature of Figure 3 is the fact that the differentials which existed in 1918 between the F_1 hybrid diffusion rates of East and West Japan, and also traditional and late-developing regions, have completely disappeared by 1923 as a result of extensive progress of diffusion in conservative prefectures. This was the result of the rapid diffusion in two different groups of prefectures in East Japan: the first was the sericulturally backward prefectures in the north such as Hokkaidō, Aomori and Iwate; and the second the major sericulture prefectures of Nagano, Yamanashi, Shizuoka and Chiba. These developments are distinctly depicted in Figure 3 in terms of the distance

[41] The number of publications are calculated from K. Ishikawa (ed.), *Nihon sanshi-gaku bunken-shū: 1676–1937* [A Bibliography of Sericulture Science in Japan: 1676–1937], Meibun-dō, 1940, and Sanshi Kenkyū-kai (ed.), *Sanshi kankei shoseki shozai mokuruku, I* [A Union Catalogue of Sericulture Related References, I], Sanshi Kenkyu-kai, 1977. These publishing activities reached a peak in the years between 1917 and 1919, when 13, 8 and 10 tiltes on F_1 hybridization were released in 1917, 1918 and 1919 respectively.

[42] Sericulture-related publications were quite frequently produced particularly in Nagano, Gunma, Aichi, and also in Fukushima, Saitama, Gifu and Hiroshima. Some notable books and pamphlets were published as well by the Date and the Ueda Egg-production Cos., the egg-breeding stations in Aomori and Saitama, and the Silkworm-egg Trade Association of Yamanashi. The Katakura Co. published a journal *Sangyō no Nihon* [Sericultural Japan] to promote diffusion activities, in addition to the well-known pamphlet by the company's technician, T. Saitō.

FIG. 3. PROGRESS IN DIFFUSION OF THE F_1 HYBRID
(Prefecturewise, Total, from 1918 to 1923)

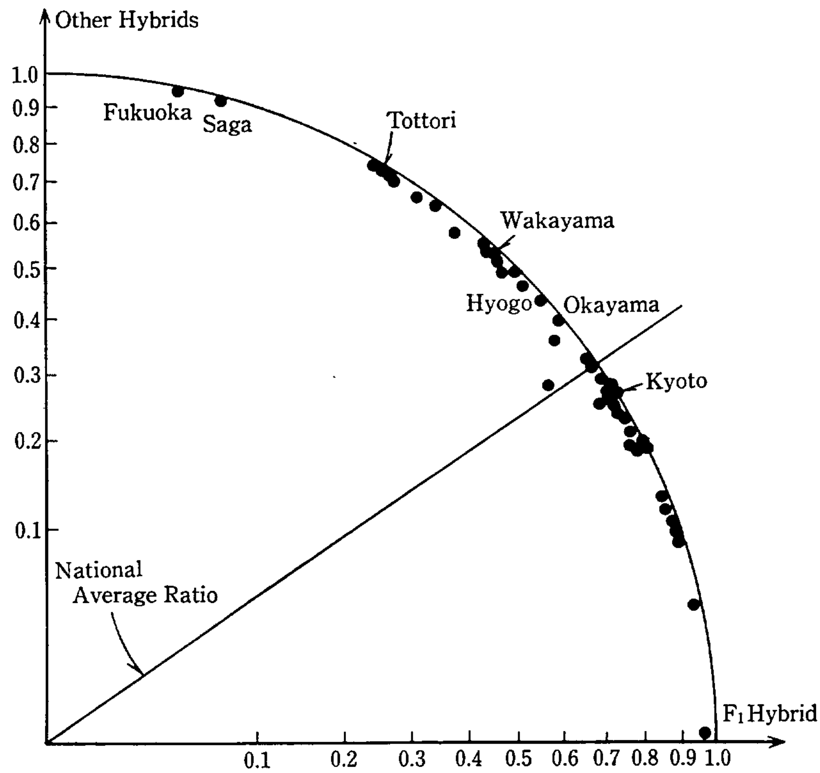


Source: Sangyō torishimari jimu seiseki, 1918 and 1923.

from the 45° line. Consequently the previous difference in diffusion rates between East and West Japan was totally eliminated, as can be seen in the average rates of both districts.

Secondly a brief comment should be given to the fact that some western prefectures, such as Fukuoka, Tottori, Saga, are located far below the 45° line. That is, the diffusion rate of F_1 hybrids (the weighted average of all rearings) in 1923 in those prefectures had declined below the level recorded in 1918. This phenomenon appears to be a little paradoxical, but a careful examination of the data reveals the real cause of these declines. The decreases in the F_1 hybrid diffusion rate originated from very low rates of F_1 hybrids in the summer-autumn rearing. These arise mainly owing to a problem of definition. The composition of the F_1 hybrid and other hybrids in summer-autumn rearings in each prefecture is plotted on binomial probability paper in Figure 4 for the year 1923. This diagram shows that the proportion of other hybrids in the above-mentioned prefectures was quite high, as expressed by the cosine value on the vertical axis (the proportion of F_1 hybrids as a sine value on the horizontal axis). The distance from the origin measures the total proportion of all hybrids, hence the residual gives the proportion of non-hybrids (i.e. fixed varieties).

FIG. 4. RELATIVE SHARES OF THE F_1 HYBRID AND OTHER HYBRIDS (Summer-Autumn Rearing in 1923)



Note: Data are plotted on the binomial probability paper.
Source: *Sangyō torishimari jimu seiseki*, 1923.

Accordingly Figure 4 tells us that as early as 1923 almost all summer-autumn rearings were already of hybrid varieties in most prefectures.

Furthermore we have an additional useful information as to the production of other hybrid varieties. That is, around 1923, the most popular form of crossing among "other hybrid" varieties for summer-autumn rearings was the so-called "3-way hybrid." As is well known, the 3-way hybrid is a hybrid having an F_1 for one parent. Hence, although it was classified as a non-F_1 hybrid (i.e. one of the other hybrids) in the statistics, the hybridization technique used definitely presupposed the principle of cross breeding for the first filial hybrid. In those days more than 90 percent of other hybrids was said to be 3-way hybrids,[43] and orthodox F_1 hybrids, such as the bi-bivoltine or uni-univoltine F_1 hybrid, came to prevail soon after 1923 even in summer-autumn rearing varieties. Thus, if the 3-way hybrid is re-defined as an F_1 hybrid in an enlarged sense for the above reason, then by 1923, 98 percent of

[43] *Sanshi tōkei nenkan* provides the exact figures. For example, as late as 1929 when the popularity of 3-way hybrids had almost passed, more than 90 percent of "other hybrids" were still of this type.

spring rearing varieties and 96 percent of summer-autumn rearing varieties were already of F_1 hybrids. In other words the diffusion of F_1 hybrids, which started institutionally in 1915, was almost completed within less than ten years. This extremely rapid diffusion was without doubt one of the greatest achievements in the history of development of Japanese sericultural technology.

The dynamic leadership of large silk-reeling filatures was pointed out previously as a result of the probit analysis to be the most important factor in the achievement of the rapid diffusion of F_1 hybrids. Finally, however, a crucial background element should be mentioned to understand their strong leadership. This was due to a change in the demand factor in the raw silk market; in the 1910's the demand for raw silk in the United States, Japan's largest export market, began to shift towards high-quality thread, and this tendency was accelerated by the appearance of artificial silk, since coarse threads could not compete with the latter in price. It, therefore, was an urgent problem for the Japanese raw silk industry to grasp exactly the changes in the demand structure, and to remodel its production technology in order to adapt to new market conditions. In this respect the reeling filatures were best placed to react to this necessity. It was in fact this factor that led to embark upon the production of silkworm-eggs by themselves.

More specifically, to produce cocoons of superior quality was indispensable for producing high-quality fine threads. Cocoons of uniform quality in sizable quantities were also required to insure the production of raw silk with adequate evenness. From the viewpoint of management as well, in order to adapt sufficiently to the wide fluctuations in raw silk prices, and to the changing demand for yellowish raw silk, it was quite reasonable for silk reeling filatures to try to solve these difficulties by producing appropriate quality silkworms. Hence they were, as a matter of course, quite eager to introduce the high quality F_1 hybrids. The large filatures with sufficient reserves proceeded to set up modern egg-production facilities and also distribution networks of hybrid varieties to sericulture farmers. Through these networks precise guidance on rearings was offered by the company's qualified specialists in order to mass-produce high quality cocoons. On the other hand, for the sake of the efficient management of this system, it was necessary for them to encourage the so-called conditioned weight transactions based upon objective standards, and to establish special subcontract sericultural associations through which to realize the filatures' aims.

In the egg production market, the development of new varieties and their characteristics became more sensitive and exact in reflecting market conditions as a result of the entry of the raw silk producers, who were the most sensitive to changes in raw silk demand. What is more, these new-comers were busy with developing new varieties to meet future trends in demand. Thus their R&D activities contributed significantly to raising the technical level of egg production, and they also came to control to a large degree the orientation of the silkworm-egg production industry as a whole. For instance, high yielding varieties of cocoon which appeared in the early years of Shōwa were developed almost exclusively by the big raw silk manufacturers such as Katakura, Gunze, Shin'ei and Shōwa. These facts testify to the high technical competence achieved by the manufacturers in this field.

No one can deny that the sericultural and silkworm-egg production industries became more market-oriented, and the price mechanism also became more effective in these markets as a result of the entry of silk-reeling filatures into the egg production market. On the other hand it must be pointed out that these big manufacturers were inclined to oppress sericulture farmers' interests because of their self-centered production policies. As negotiating from the weaker position, sericulture associations and farmers could not often reject unfavorable trade terms and found themselves forced to take over the manufacturers' risks. Such a tendency for farmers' interests to be neglected appeared especially after the early Shōwa period when the special subcontract system in the cocoon trades became widespread.[44] Where special subcontracts were involved, not only did silk-reeling filatures provide technical guidance, but in many instances they also supplied credit to farmers, and this made the farmers' situation all the more vulnerable. Although these kinds of negative effect should be kept in mind, the contribution of silk-reeling manufacturers to the diffusion of F_1 hybrids must be highly evaluated. Since the leadership provided by them was the most important factor in the achievement of the extremely rapid diffusion of this epochal new variety.

IV. *Concluding Remarks*

So far the various factors which promoted the diffusion of the first filial hybrid silkworms have been discussed in the context of their historical backgrounds and through statistical analysis. Finally we may summarize the conclusions obtained and draw out their implications from a slightly broader perspective. In the early years of Taishō, the F_1 hybrid silkworm was first developed and immediately began to be diffused. The diffusion rate of F_1 hybrids in the wider sense, viz. including the 3-way hybrid, stood at less than 50 percent in 1918, but quickly reached 97 percent by 1923, a mere five years later. Regional differences in the rate among different sericultural regions had disappeared by this time, and silkworm varieties reared by sericulture farmers were almost without exception F_1 hybrids. That is to say, the diffusion of the epoch-making F_1 hybrid was completed in less than ten years. This is an almost unparalleled example of rapid diffusion among the world's technological innovations. To be sure, when compared with the hybridization of other agricultural products, the control of silkworm crossing was easier from a technical point of view, and many environmental factors could be eliminated. Hence the conditions for rapid diffusion may be said to have been relatively favorable. But the exceptionally fast pace of diffusion cannot be attributed to technical causes alone. The process must be thought of as being governed throughout by more fundamental socio-economic factors.

To clarify this point, probit analysis was adopted and applied to the cross-section data of 1918 in order to extract the socio-economic factors accelerating the F_1 hybrid diffusion. It is worth remarking that two of the factors examined statistically proved to be of particular importance: (1) the prominent role played by the large silk-reeling filatures in developing the new hybridization technology and reorganizing their production systems; and (2) the educational and R&D activities for permeating new crossing techniques and knowledge of F_1 hybrids. By checking the data for each prefecture, these factors were seen to provide also a sufficient explanation of why there existed relatively large differences in the diffusion rates of F_1 hybrids among different sericultural regions. Our statistical analysis also suggests the somewhat more general implication that the speed of diffusion of new varieties

[44] See, for instance, H. Akashi, *Kindai sanshigyō hattatsushi* [A History of the Development of the Modern Sericulture Industry] (Meibun-dō, 1939), pp. 403–06. The author was a former official of the Ministry of Agriculture and Forestry, and his views are well worth consulting for this reason.

was in fact dependent upon the degree of development of regional markets.

If the above explanation of the rapid diffusion of F_1 hybrids is accepted, we are led to a radically different evaluation of the promotors of diffusion activities from the commonly held. That is, the prevailing view that the diffusion of prewar agricultural technology was always realized by means of political subsidies, in accordance with the authoritarian policy of the Government, seems to be totally incorrect, at least for the case of the diffusion of the F_1 hybrid. This has been distinctly confirmed not only by our statistical findings but also by the close examination of individual historical facts. For instance, such evidence as the long-standing attempts to improve indigenous varieties, the technical guidance tours by sericulture instructors voluntarily provided by egg-manufacturers, the sericultural training schools and lecture courses financed also by them, provides crucial counter-examples to the prevailing view.

In other words it is no exaggeration at all to say that such independent enlightening and improving activities by private producers, together with the highly competitive character of the egg and cocoon markets, were the real underlying factor behind the very rapid diffusion of F_1 hybrids. Since these historical facts alone could account for the founding of R&D departments in the egg-production companies and of prefectural egg-breeding stations almost simultaneously with the establishment of a national station network. They also explain why a considerable portion of the parent-eggs for F_1 hybrids was developed by private producers independently of the available eggs supplied by the central station, and this resulted in giving a great stimulus to the research conducted at the national experiment stations. Similarly, with respect to sericultural education, it should be noted that, while a public technical education system was successfully created at the beginning of the 20th century, privately organized industrial schools as well played a decisive role especially in the earlier period of agro-sericultural education. In short it is our understanding that the exceedingly rapid diffusion of F_1 hybrids could not have been realized by the coercive diffusion policies of the government alone without the support of competitive markets and the active entrepreneurship of private producers.

The above understanding is not meant to discount the importance of the role of the sericulture experimental stations, the sericulture control centers and other public sericultural research institutes in promoting the diffusion of F_1 hybrids. On the contrary their active role in advancing the diffusion should be more appreciated when one takes into account the difficulties involved in egg-breeding techniques as a part of agricultural technology. Compared with the diffusion of silk-reeling technology, our analysis of F_1 hybrids indicates two important common features in the diffusion of sericultural industry technologies. That is to say, in both cases the initiatives of large silk filatures and demand factors in the raw silk market were of fundamental importance in influencing the timing of the introduction and the speed of diffusion of new technologies.

On the other hand agricultural technology, unlike manufacturing technology, normally requires huge R&D investments for the systematic development of technological innovations. In the case of silkworm hybridization, hence, the role of public educational and R&D institutions was inevitably crucial. In other words the so-called competitive development or imitating innovation by individual firms, which characterizes the development of manufacturing technology, is less possible in the field of agricultural technology. Consequently institutionally established routes for the dissemination of technological information played a key part, and diffusion promoters were often regarded as terminal organs of the hierarchical institutional system of diffusion rather than independent market forces. Nevertheless, this is not to imply that diffusion activities were always supervised by the authorities, or that there existed no grass-roots voluntary efforts for the diffusion of new sericultural technologies.

In any event the unique features of the diffusion of processes of agricultural and manufacturing technologies present a very interesting contrast, and further detail case-studies are needed. It can finally be pointed out, from a broader perspective, that the extremely rapid diffusion of F_1 hybrids could be regarded as a product of the relatively homogeneous society of Japan. Since such a society is, as a rule, very competitive in adopting innovations and efficient in transmitting information. Although these features are necessary conditions for an efficient market mechanism, we Japanese should not forget also the reverse side of the coin, the fragility of such a society which was the basis, for instance, for Japanese fascism during World War II.

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