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Printed in Japan

ISBN 92-808-0253
ISSN 0379-5780

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HSDRJE-46/UNUP-253

THE DIFFUSION OF NEW TECHNOLOGIES IN THE JAPANESE SERICULTURE INDUSTRY : A STUDY ON THE EXPERIENCE OF HYBRID SILKWORMS

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I. INTRODUCTION — THE JAPANESE SERICULTURE INDUSTRY AND ITS TECHNOLOGICAL DEVELOPMENT —

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

Nowadays it is commonly understood that such rapid progress of the Japanese sericulture industry was realized mainly by the continual technological innovations as well as rationalizing the production organizations. The prevailing reeling machine was a typical appropriate technology combined the transplanted steam-reeling machine with the indigenous hand-reeling one. It was again improved step by step in various parts, and remodelled into the so-called multi-ends reeling machine in 1920's. The cocoon dryer and cooking-machine were equally improved a lot and contributed to increasing the productivities. These development of filature technology and the expansion of the industry as well required the increase in cocoon production and the improvement of cocoon quality.

The first requirement was mostly statisfied by the rapid progress in summer-autumn rearings since 1900. The second one was met by the epochal realization of the first filial (F_1) hybrid silkworms in the mid-1910's. Namely the production increase and quality improvement of cocoon were also realized by the remarkable technological changes due to the domestic R&D activities, not to the imported innovations. In particular it is no overstatement to say that the development and rapid diffusion of F_1 hybrid silkworms were the most important 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 F_1 hybrid and also to determine the dominating factors for its rapid diffusion are the main purposes of our present analysis.

This problem-raising will cast the light upon the following two important aspects. First, the diffusion speed of F_1 hybrid silkworms was extremely high, compared with other countries' experiences, for instance, the famous example of the hybrid corn in the United States.[1] The latter had to spend more than a quarter of the century to complete the diffusion despite its much later commencement, whereas the case of F_1 hybrid silkworms in Japan was almost completed its diffusion merely within 10 years. In various places of the Japanese economic history, it is easily observable for new technologies to have realized very rapid diffusions. In other words such rapid diffusion of technological innovations is one of the unique and important characteristics of the Japanese economy. Our analysis on F_1 hybrid silkworms will help to understand the Japanese features of diffusions general, which remains to be inadequately studied despite the quite important roles it played for promoting the

Japanese economic development.

Secondly, our analysis may raise a doubt to the conventional appraisal for prewar agricultural policies by the Government that introductions of new technology were almost compulsorily implemented under the authoritarian guides of the Government.[2] Since many evidences in our analysis suggest that quite active responses of the broad bottom (i.e. large to small cocoon producers) to the new technology were the very factor to realize the rapid diffusion of F_1 hybrid silkworms. It prepares an answer for the question whether such centrally imposed bureaucratic guidance was really the unique force of promoting speedy diffusions. Although the systematic network of experimental stations was so far emphasized its negative effect as a part of the so-called "industrialization from the above" in the economic history, the great positive effect for encouraging the local responses in the process of diffusion should not be disregarded. Besides our study on R&D activities and sericultural education in the private sector may reveal some significant characteristics for 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 years from 1914, the date marking the first distribution of the parent-eggs for F_1 hybrid silkworms, to 1929 from which time a new type of hybrid varieties became prominent after completing the diffusion of basic F_1 hybrids. Most important information is available in the annual report _Sangyō torishimari jimuseiseki_ [Statistical Annual on Perbrine Inspection of Silkworm Eggs] published from the Ministry of Agriculture and Commerce during the said 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 the probit analysis shall be applied to the cross-section data of the year 1918, when the variation of diffusion rates among various prefectures was still wide enough to extract the factors for determining the diffusion 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 of hybridization in the Japanese sericulture industry. Such a broad and strong tradition induced the integration movement of cocoon varieties which subsequently realized two important bases for rapidly diffusing F_1 hybrid silkworms. Namely they were the network of sericulture experimental stations and the active involvement in the silkworm-egg production industry by big silk-reeling filatures. In Section II, the determinant factors for diffusions of the F_1 hybrid which was absolutely superior to the indigenous varieties shall be grasped by the probit analysis. It reveals the significance of big silk filatures' initiatives and the important roles of technical education and R&D activities as well. Accordingly actual activities of the related fields will be lastly examined to endorse those effects extracted by the statistical analysis.

II. THE BIRTH AND DIFFUSION OF THE F_1 HYBRID SILKWORMS

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

1. Historical Background of Hybridization and the Role of Silkworm Egg Producers

The Japanese sericulture industry had a long-standing tradition of crossing the silkworms, although it was not until the early 1910's that the mass-production of F_1 hybrid silkworms was realized for practical use, since the crossing had to embody the heterosis (i.e. hybrid vigor) based upon the scientific rigorousness of heredity by Mendel's Law. One of the oldest written records in existence equally proves that the hybrid of spring and summer rearing silkworms was produced and had obtained a high reputation in Nagano Prefecture as early as in 1845.[5] The existence of vernacular technical terms meaning the crossing or hybridization in various parts of Japan endorses again that the cross-breeding of silkworms was already a wide spread practice in those days of Japan. The crossing for 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 quickly revive and, for instance, eight different cross-breeds were already listed at the Yokohama Cocoon Sample Fair held in the following year, 1879.[6]

Such a 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 when small cocoons of pale-green varieties (e.g. Seihaku) were preferred, since they were relatively easy for sericulture farmers to rear. In 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 (viz. this time, Koishimaru) had staged a comeback and was fashionable until the end of the century. After the turn of the century, medium size 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 not a few outstanding improved varieties were produced through cross-breeding in the process of frequently changed preferences. Some of the more famous examples of such hybrids are Sekai'ichi (the Aojuku line), Hakuryu (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. The foreign silkworm eggs were imported by the Hokkaido 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 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 provide a tremendous stimulus to many egg-producers and sericulture farmers, as known from the fact that a number of excellent Sino-Japanese hybrids were produced in 1890's by the progressive producers of main sericultural areas. For instance, those typical hybrids were Tsunomata developed in Ibaragi and Tochigi Prefectures, Kakushina of Kanagawa, Shinamata of Fukushima, Round Matamukashi of Saitama, etc. Meanwhile, a sericulture expert, N. Imanishi, at Yokohama Raw Silk Conditioning House brought back Euro-Chinese hybrid with him from Italy to open the way for rearing European races. The Sanryusha Co. of Aichi Prefecture who were provided the hybrid from him successfully developed by selective breeding the first Euro-Japanese hybrids, Kōsekimaru and Sanryumata, which were said to be more adapted to the climate 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 to be a kind of fixed strain amplified through cross-breeding technique rather than the non-repeatedly reproduced generation from the pure parent eggs. As occasionally pointed out, silkworm-egg producers kept in their hand the F_1 hybrid with heterosis as the parent eggs, and the F_2 or subsequent generations were sold to sericulture farmers mainly because of easier successive reproductions. Consequently there existed two opposite appraisals as to the quality of these hybrid cocoons among sericulture farmers and silk-reeling filatures. The one was a favourable 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 another view, widely held among sericulture farmers,[7] evaluated the technique negatively, since the hybrid silkworms were frequently faced bad crops owing to its instability by nature.

This divergence of opinions was closely related to the very fact that, as now confirmed, the hybridization technique in the Meiji period was never developed under the heterosis theory of F_1 hybrids based upon the Mendel's Law. The F_1 hybrids 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 not following the exact procedures of cross-breeding for heterosis was equally inclined to encourage the proliferation of inferior silkworm varieties. However, despite the existence of two opposite viewpoints and results, what should be emphasized is the competitive nature of the egg-production market and the vigorous entrepreneurship which led to continual efforts to improve existing varieties and gave the market its special dynamism. Specifically speaking, it was the progressive silkworm-egg manufacturers who promoted the technical education and establishing the diffusion network which were quite poorly supplied in the society of those days. Hence one cannot correctly appraise the significance of conventional improved-varieties without referring to this basic fact.

In the second half of 19th century, the educational and diffusion activities related to sericulture technology were organized almost exclusively by the producers of silkworm eggs. Namely the rapid development of the Meiji sericulture industry greatly owed to the promotional efforts provided by those egg-manufacturers. Since agro-sericulture schools and vacational centers were not set up on a systematic basis by the authorities until after the turn of the century. Even then, the instructions offered there mainly aimed at giving the specialized training for agricultural school teachers and lower techno-bureaucrats, not at giving the practical guides for improvements of agro-sericultural technology. Thus the active initiatives of enlightened egg-producers assisted by veteran sericultural farmers were actually responsible for filling this gap. They provided the broad technical guidance closely tied with production, and promoted to diffuse new technical knowledge through educational activities at the local level.

Typical two examples of this kind of egg-manufacturers (dealers as well) are the Takayama-sha Co. of Gunma Prefecture and Kyōshin-sha Co. of Saitama, both of which contributed substantially to the spread of warm-room-rearing technique. From early Meiji, the two companies sent a lot of sericultural instructors to the study-circles and gave lecture sessions organized in various parts of the country. Moreover they set up technical training centers in their own sites and turned out a large number of sericultural experts from their intensive courses. By 1892, at least 6,000 of these technicians had already been trained, and by 1907 the number of their graduates is reported to have reached 40,000.[8] Several other outstanding training centers were established also 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. It does not mean of course that in their activities there were no problems of the quality for graduates 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 the new technical knowledge of silkworm breeding and rearing.

2. The Dawn of "Experimental Station Technology"

It should be noted that beyond the dealer's sales promotion policy, there existed fully justifiable reasons for such 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 to be ameliorated by adapting the various varieties respectively to regional climate and geographic conditions. In particular the summer-autumn rearings were frequently bad crops, and the diffusion of those improved varieties were still incomplete. Appropriate varieties for stable crops were keenly needed to be developed by trial and error. Thus it was entirely reasonable that silkworm-egg producers should experiment with the breeding and rearing of different varieties.

On the other hand, the cross-breeding and variety improvement gave rise to many new varieties of silkworm, and led to the great diversification of a large number of varieties in various parts of Japan. This trend, coupled with changing preferences for specific varieties, produced the wider variations in cocoon quality. Although the precise time-series data on the types of cocoons produced during the Meiji period are not available, even an inference drawn from fragmentary evidences makes it quite clear that a very large number of varieties were taken in rearing in 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 hundreds separate types of cocoon were then 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 the figure 1,593 as the existing cocoon varieties.[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 be sorted out and standardized. As early as 1890's apprehensions had been already expressed over the extremely diversified varieties of silkworms. Meanwhile the uniform quality of Japanese raw-silk was more strongly requested 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 eventually due to the production of so many different kinds of cocoons. This view should be somewhat discounted, since it reflected the overwhelming negotiating power of reeling filatures over sericulture farmers in purchasing cocoons. The variation in quality of different cocoons was in effect not necessarily so great for a number of varieties, even though they were assigned different names. Nevertheless one cannot deny that there existed too many varieties of different silkworms, and not a few of them were reared merely in small scales.

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 the strong pressures from silk-reeling filatures who experienced the drastic fall in raw-silk prices of 1907. But there had already existed two basic underlying factors which dominated the direction of the government policy. First, the indispensability of control and management for the parent and grandparent eggs of F_1 hybrids was gradually realized, as the overwhelming superiority of F_1 hybrids by an application of the Mendelian heterosis theory was steadily established. The second factor was the independent establishments 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 enacted the Sericultural Industry Law.[12] It was the dawn of "Experimental Station Technology" era from the previous age of "silkworm-egg dealers' (producers') technology."

In other words the government policy so far is considered to have been essentially passive under the rapid development of the sericulture industry. This characterization is easily confirmable from the conservative nature of the laws and ordinances serially enacted in the field. For instance, following the Silkworm-Egg Control Ordinance of 1873, the Government passed the Silkworm-Egg Inspection Act (1886) to strengthen the control over the perbrine infected eggs. It was developed in the subsequent years to the enactment of the Silkworm-Egg Inspection Law (1897) and to the Silkworm Disease Prevention Law (1905). All of these were designed primarily to control and prevent the perbrine, not to encourage the improvements of cocoons and silkworm-eggs. After the year 1905, the radical change in policy came about and a more positive policy was adopted to develop the sericulture industry. Such a change was said to be based upon the advices of All Japan Raw-Silk Association in 1909 and Inquiry Committee for Production Survey in 1910. Simultaneously it inevitably resulted from the fact that the level of breeding techniques had reached the point where they could be no longer 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 counsels provided by the techno-bureaucrats and sericulture academics who were members of the authorities concerned or its advisory committees. It is, for instance, observed from the fact that the National Institute of Silkworm-Egg Production immediately started the research on F_1 hybrids, which was still at the 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 are reminded of the superiority of F_1 hybrids and their great practical utility having been demonstrated in strict genetic terms exactly a few years earlier. Namely K. Toyama, an authority of insect genetics, had repeatedly carried out the experiments of crossing Thai and Japanese silkworms in Bangkok where he was temporarily in office of the head of the Raw-Silk Bureau in Thailand's Ministry of Agriculture, and of Thai Royal School of Sericulture. It was in 1904 that he succeeded in confirming the applicability of heterosis by Mendelian Law to silkworms as well. The research, following closely on the rediscovery of Mendel's contributions in 1900, was a pioneering achievement in the early practical application of this 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 the industrial journals to disseminate as widely as possible the distinct advantage of 'the F_1 hybrid by itself.' Meanwhile, through his scholarly contributions to the 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 had energetically set about applying the heterosis theory to concrete ends of the industry. Specifically speaking, 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 establishments of local government's egg-breeding station prior to the central one, aiming at own distributing 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 days in improving varieties, set up the first silkworm-egg breeding station of the local government 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 respectively started producing and distributing independently silkworm-eggs of local varieties prior to establishing the National Institute in 1911. For a more detail information, the reader is referred to the work, Sanpinshu ni kansuru chōsa [A Survey of Silkworm Varieties], but those eggs distributed by local stations were, as a rule, those of indigenous fixed strains already well-adapted to the local conditions and prevailing in each region. Typically popular varieties of such types were, Matamukashi, Improved Matamukashi and Aojuku in a univoltine strain, and Ōkusa, Hakuryu and Aojuku in a bivoltine strain.[14]

In parallel with establishing the National Institute of Silkworm-Egg Production, the creation of prefectural egg-breeding station was strongly urged by local governments. In 1914, when the National Institute began distributing the parent eggs of F_1 hybrids, local breeding stations as the recipients had already set up in 26 prefectures. It is, therefore, very important to stress the following aspect in connection with the rapid diffusion of F_1 hybrids, viz. the existence of such grass-rooted movement to improve and standardize silkworm varieties in various prefectures greatly contributed to accelerating the diffusion speed of F_1 hybrids. Since, in the process of it, a part of the well-organized network for local diffusion had been established before commencing the nation-wide distribution of F_1 hybrids.

B) The Superiority of F_1 Hybrids and Its Diffusion

1. The Commencement of Egg-Distribution by Experimental Stations

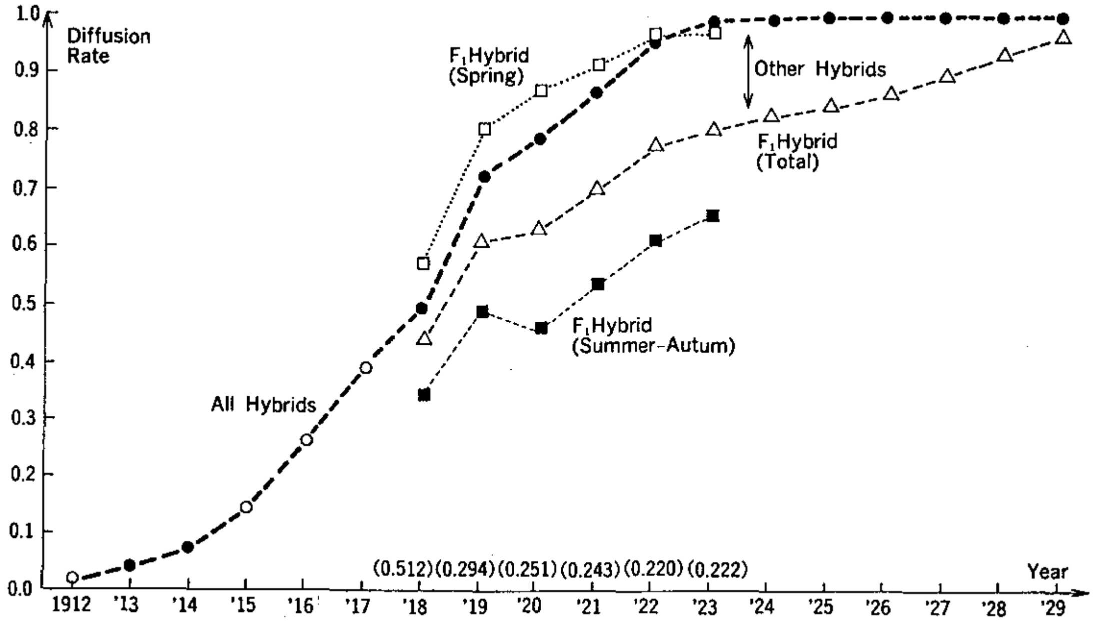
Immediately after their establishment, the National Institute and its four branches started the works of the pure line separation, and scientifically confirmed as early as in 1913 the distinct superior qualities of F_1 hybrids by the variety test over 48 different fixed and hybrid varieties. Of the F_1 hybrids examined, a Sino-Japanese hybrid, Aojuku-by-Daiento, 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 days of feeding period, the percentage of missing larvae was smaller, and the cocoons had the higher percentage of raw-silk with easier reelability. These traits were reconfirmed at about the same time by the Second Nagano Prefecture Station of Silkworm-Egg Breeding. 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 the 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, while 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. For the first year, only 1,084 silk-moths of six varieties were distributed with the recommendation of 12 authorized combinations for crossing. But the significance of distributing the parent eggs for F_1 hybrids by government's institutions was of great importance for the development of the Japanese sericulture industry. The parent eggs were presumably passed on to private egg producers via the local egg-breeding station in 1915. Hence the first production of F_1 hybrids in Japan is considered to have been in the spring of 1916.

While the distribution of mother moths for summer-autumn rearings was first made in 1915, the number of total moths transferred from the central station in the year was greatly increased 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 authorized combinations of hybridization for the obtained moths were substantially expanded as well. This reflected also in another aspect that the mother moths distributed by the central station, which in 1915 accounted for only 1.7 per cent of the moths produced independently by the prefectural egg-breeding stations, were increased to 44.2 per cent in 1917 and 53.1 per cent in 1918. Namely the former strains occupied the majority of distributed eggs to private producers as early as in 1918.[16]

As shown in Figure 1, the diffusion of the F_1 hybrid was steadily progressed among various prefectures. However, despite its rapid success, the F_1 hybrid had not necessarily no problems. Two points are better to be mentioned. First, the producing method of F_1 hybrids was much more complicated and labor intensive than of the traditional fixed varieties.

Fig. 1 Progress in Diffusion of Hybrid Varieties



Note: (1) The O of all hybrids stands for an estimate from the normal probability paper.
(2) Figures in parentheses show the coefficient of variations.

Sources: Sangyo Torishimari Seiseki, 1912-17, Sangyo Torishimari Jimu Seiseki, 1918-29, and Sanshigyo ni kansuru Sanko Shiryo, Dai 3-ji.

For instance, as the eclosion timing 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 the timing of it. Moreover, to minimize unsuccessful copulations, it is indispensable to identify the sex of each pupa as accurately as possible, whether by the weight method or by the pupa inspection method. Thus the adequate technical knowledge and equipment were a first requisite for successful productions of the F_1 hybrid by the rather complicated method of one-batch rearing. Besides, its production and rearing required a minimum scale enough to insure suitable profits. Consequently, smaller egg-producers who could not meet the two preconditions were gradually eliminated from the market during the diffusion process. And the average size of egg-manufactures in the subsequent years expanded substantially because of the very result.

Secondly, the F_1 hybrid for summer-autumn rearings was not regarded to be greatly more advantageous than 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 rearings, as even the central station strains for summer-autumn F_1 hybrids had to repeat 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] meanwhile traditional varieties adapted to the specific conditions in each region were generally preferred and encouraged. Namely, as 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] It is shown in Figure 1 that, hence, the diffusion rate of summer-autumn F_1 hybrids was appreciably lower than for spring F_1 hybrids. It was still only 66.7 per cent in 1923, and the completion of diffusion was not realized until around 1929. Or it is definitely implied that the summer-autumn F_1 hybrid as a stable and superior variety was broadly accepted among various prefectures after the coming of the artificial non-hybernating egg era due to the artificial hatching technique.

2. Important Roles by Big Silk Filatures in the Diffusion Process

Technical difficulties of producing F_1 hybrids were steadily overcome, as producers became better acquainted with its cross-breeding techniques under the energetic guidance of the central and local experimental stations. And behind the rapid development of F_1 hybrids existed the overwhelming superiority of the F_1 hybrid over other varieties, which by itself could 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 per cent of all varieties reared. Particularly, in the case of spring F_1 hybrids, its diffusion was almost completed by this year as 97.8 per cent of all spring rearing varieties was occupied by the F_1 hybrid silkworms.

Such a 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. it must be equally sought among 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 even greater interests in hybrids and foreign races. A new movement now became active in developing the hybrids and improving the existing varieties by their own hands.

Although the information on hybrids prior to 1918 is not sufficient at all, the basic trend in hybridization is confirmable from the qualitative data of variety lists for various parts of Japan.[19] In 1912, for instance, only 12 varieties out of 867 (1.4 per cent) are listed as 'crossed' or 'hybrid,' but one may find 129 out of 958 varieties

(13.5 per cent) bearing the designation in 1914. In 1916 when the first national station bred strains had appeared, as much as 971 out of 3,317 varieties (29.3 per cent) are recorded as hybrids. The variety increase of hybrids does not necessarily straight forwardly signify an exact 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, as for ten principal varieties in each prefecture, the proportion of silkworm-eggs bearing the name 'crossed' or 'hybrid' were steadily increased.

Undoubtedly not a small portion of those 'hybrids' cannot be regarded as the genuine F_1 hybrid 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 belonging to F_1 hybrids, or verifiable as such from supplementary information. It is also noteworthy that an amazing growth in the number of reared varieties was followed in parallel by the rising number of 'improved' varieties, which was an indicator of the producers' desire to develop better silkworms. Meanwhile 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 per cent in 1913, and 7.1 per cent in 1914, most of which were spring reared silkworms of Sino-Japanese hybrids.[20]

It should be sufficiently emphasized that private egg-producers had already laid the groundwork on their own initiatives enabling them to adjust and absorb technical innovations in cross-breeding under the new system, before the diffusion of F_1 hybrids started under the distribution network organized around the sericulture experimental stations. 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 endorsed from the fact that as many as 35.6 per cent 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 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. Since it was they who had strongly urged the standardization of silkworm varieties, and who were expected to gain the most from the prevalence of F_1 hybrids.

One of these well-known filatures, Katakura Silk Co. in Nagano was quick to seize upon the new development, and organized All Japan Association for Propagation of F_1 Hybrids in 1914. Actively engaging in the production and diffusion of these hybrids, Katakura became their most energetic advocate. Specifically speaking, as early as in 1914 Katakura Silk experimentally distributed 1,088 egg-cards of F_1 hybrids to sericulture farmers nearly located 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 hybrids. Namely their parent eggs of European semi-fixed races were reproduced by themselves, not obtained 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 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, conventional negative images on hybrids held by many sericultural farmers were wiped out by energetic efforts of the Company. To realize it, enlightening sessions were organized in the major cocoon purchasing regions, instruction manuals for F_1 hybrid rearing were distributed to the farmers, and professional guidance was provided by the Company's itinerant experts in the earlier phases of silkworm rearing. These technical instructions and educational activities provided by Katakura Co. must be the principal reason for the very rapid diffusion of F_1 hybrids and for persuading sericulture farmers being stubbornly inclined to traditional fixed varieties to adopt the new hybrid variety. Secondly, Katakura first introduced a kind of guarantee system whereby the company insured 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 case of rearing F_1 hybrids.[23] This system was gradually spread over all parts of the country and played a central role in assuring silk-reeling filatures the high quality cocoons of F_1 hybrids. On the other hand, however, this consignment system always reflected the power relation between farmers and filatures, and began to be used in 1930's by the latter to exploit the former.

It is easily expected that other reeling filatures than Katakura also started to take an active hand in promoting the introduction of F_1 hybrids. For instance, Gunze Silk Co., which had previously consigned the production of eggs to its subsidiary Taiseikan, began to develop new varieties by setting up a newly extended egg-producing department in 1915. It adopted a unique network system of sub-contracted farmers [Bunjō-Kumiai] for producing the designated parent eggs. At about the same time, several other big filatures as well started to join the egg-production industry, such as Ayabe Silk of Kyoto in 1917, Kansai Silk in Mie (1917), Nippon Silk in Tottori (1918), Higo Silk in Kumamoto (1913), etc. These combined filatures of reeling and egg-production in general produced silkworm eggs on a considerably larger scale than of the average manufacturer of egg production, as typically shown in the cases of Katakura and Gunze Silk Cos. Within several years they rapidly developed and began to influence the future trend of the silkworm-egg production industry as a whole.

Such a 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 silk-moths in the year. Namely it was composed of 740 thousand moths for parent egg production and 20.8 million moths for commercial eggs, which accounted for 13.0 per cent and 13.8 per cent of the total moths of respective productions in Japan. It should be equally pointed out that most of those 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. Since, to produce quality cocoons, the farmers' rearing process from incubation to mounting was strictly controlled by the filatures' administrations, based upon long experiences of improving varieties and also the special sub-contract system.

III. PROMOTING FACTORS FOR THE RAPID DIFFUSION OF F_1 HYBRIDS

A) A Grasp by the Probit Analysis

1. Variables and an Estimated Result

So far in Section II, we had confirmed from the aggregated data a fact of the extremely rapid diffusion of F_1 hybrids and the basic characteristics in their diffusion process. It was equally mentioned as supporting evidences for the basis of rapid diffusions 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 around the national and prefectural sericulture experimental stations, and (3) the swift adoptions by leading silk-filatures and their own diffusion promoting activities were particularly important infrastructures to realize the rapid diffusion of F_1 hybrids. Accordingly a more rigorous and thorough-going analysis taken into account the direct factors to introduce new varieties as well as the above-mentioned institutional aspects is preferable to determine exactly the contributing factors for diffusing the F_1 hybrid.

For this purpose, the probit analysis shall be applied to the prefecture-wise data of 1918 when the diffusion of F_1 hybrids were still in a relatively early phase. More specifically, there exist two reasons for the year 1918 to be selected. First, it is the first year when Statistical

Annual on Perbrine Inspection of Silkworm Eggs began to provide the detailed information on F_1 hybrids by prefectures. The second reason is that the year is the most appropriate to identify the main factors determining different diffusion rates among prefectures, as suggested by values of the coefficient of variation in Figure 1. Since the latter sharply declines after 1919.

Again there exist two reasons for the probit analysis to be adopted, notwithstanding its estimated result is not so much different from that of the simple linear regression analysis. The first is that, although the available data on F_1 hybrids are on aggregate information by prefectures, each egg-producer was making the binary decision whether to introduce F_1 hybrid or not behind the aggregation. Hence the data could be more reasonably interpreted as the collection of such binary decisions in each prefecture. Besides, the prefecture as an administrative unit could have positively justifiable significance for sericulture technology. Since the diffusion activities were closely related to prefecture-unit activities, such as self-supply policy of silkworm eggs in some prefectures, the existence of sericulture experimental station as an information center, Government's sericultural subsidies, the network of trade associations, agro-sericultural education, etc.

Secondly, the decision-making whether to introduce F_1 hybrids is supposed to be normally distributed around some critical value, which can be expressed as an integrated index of different motives to promote the diffusion. In other words, when the diffusion phenomenon is grasped as the accumulation of such response patterns to the overall effect of different factors, it is expected to have the well-known S-shaped growth curve. Consequently it will realize a far better fit to adopt a non-linear, normal c.d.f. curve rather than a linear regression line. In addition to these, the result becomes comparable with our previous analysis on the diffusion of the multi-ends reeling machine, where the probit analysis is applied as well owing to the 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 promoting factors for the diffusion of F_1 hybrids. The first two variables are related to the technological level of egg-production, viz. the average size of egg-production by prefectures $[x_1]$ and the self-sufficiency rate of silkworm eggs in each prefectures $[x_2]$.[27] The former is regarded as an indicator of modernization for silkworm-egg manufacturers, and the latter being considered to measure the advancedness of egg-breeding technology, since egg-exporting prefectures must enjoy superior technology to egg-importing prefectures. In these variables, figures for the quantity produced should be naturally adopted the previous year's one. The third variable introduced is the proportion of special subcontract transactions by prefectures $[x_3]$,[28] which can be regarded as a proxy variable to measure the influences of reeling filatures over sericulture farmers. Because of data unavailability, the figures are substituted by the data of 1928, the first year for which the information became available. But this expedient appears to be adequate for our immediate purpose.

The next group of variables is concerned with educational and R&D activities for sericulture technology, viz. the sericultural technician cost $[x_4]$ and the sericultural education intensity $[x_5]$. The former is a flow variable of the proportion of technician cost in overall sericulture-related expenditure in the local government budget, whereas the latter is a stock variable of the accumulated number of sericultural school graduates deflated by the total area of mulberry fields in each prefecture.[29] One dummy variable is introduced to measure the progress of institutional network for the diffusion of F_1 hybrids. It can be regarded as a kind of an index for the earlier starter of parent-egg's distribution [x_6]. Namely it is a binary variable depending upon whether the proportion of distributed parent eggs by the local experimental station is more than 20 per cent at the time of commencing 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 general in each prefecture, viz. 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 is considered to reflect the relationship between the sericulture industry and other agricultural activities, whereas the latter expressing the relationship to other industrial activities general.[30]

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

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

$$\hat{\beta}'\underset{\sim}{X} \equiv \underset{}{5.097} + \underset{(1.38)^{*}}{0.121x_1} - \underset{(-1.31)^{*}}{0.107x_2} + \underset{(2.88)^{***}}{0.220x_3} + \underset{(2.00)^{**}}{0.134x_4}$$

$$+ \underset{(2.67)^{***}}{0.209x_5} + \underset{(1.46)^{*}}{0.107x_6} + \underset{(1.96)^{**}}{0.139x_7} - \underset{(-1.63)^{*}}{0.115x_8} \quad \ldots\ldots(1)$$

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

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

2. An Interpretation of the Result and Diffusion Patterns

Some findings resulted from the estimate (1) are better to be confirmed here. First, among eight variables, the proportion of subcontract transactions for cocoons [x_3] is observed to have the greatest impact on the promotion of F_1 hybrids' diffusion. As noted above, however, its effect might be considered to be discounted to some extent, since the data for this variable is adapted from the later period. But our approximation can be justified in the twofold senses that the effect through different absolute levels 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 observed in the case of silk reeling technology, the great importance of pioneering role by 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 with education and R&D, i.e. the sericultural education intensity [x_5] and the costs spent for technical experts [x_4]. Namely it was quite reasonable that 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 could more easily understand the superiority of F_1 hybrids based upon their newly accumulated knowledge on the sericultural science and technology. In regard to the data of educational activities, the total number of sericultural graduates includes those from training centers and courses to professional sericultural schools. Many of them contributed in numerous ways to the realization and diffusion of new technology at the local level in the form of a sericultural instructor or technical expert for trade associations and local governments. The number of the graduates stands approximately in proportion to the number of sericultural instructors, the data of which becomes available after broad introduction of the license system for instructors.[32] With respect to the data of R&D activities, the technical expert costs include not only various expenses for sericultural specialists working in the silk control centers and egg-breeding stations but also the portion of technician-related costs in the silk industry promotion funds (and hence including subsidies to agricultural and trade associations as well). Accordingly one may safely conclude that these costs reflect accurately enough the general attitude toward technical orientation and improvements at local level as well as the fruits from them.

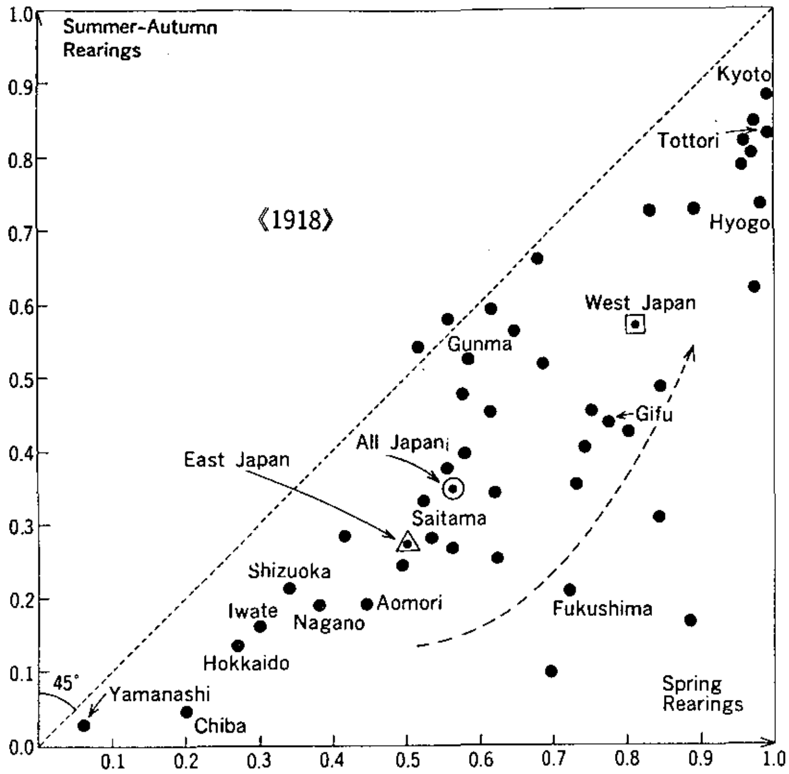
The third factor dominating the diffusion of F_1 hybrids is the environmental conditions represented as a proxy variable by the proportion of summer-autumn rearings [x_7]. Namely the higher this ratio in a given prefecture, the higher the rate of F_1 diffusions. Since the higher ratio of summer-autumn rearings implied the greater importance of the sericulture industry relative to other agriculture activities, and also the more development of the regional market with cash-crop orientation. Consequently those prefectures with the high ratios were active to introduce new technology and improved varieties. In the case of the sericulture-related subsidy ratio [x_8], another proxy variable for environmental conditions, its contribution is relatively smaller. Significant, however, is the fact that the lower the proportion of the sericulture-related expenditures in the total amount of 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 market and the diffusion speed of new technologies.

Fourthly, the role of the earlier starter index for parent-egg distribution [x_6] proves to be less important than we had anticipated. Two factors may be adduced to account for it; first, prefecture stations for egg production were able to set up the distribution system rather easily, and second, private egg producers being excluded from the index played a fairly important role in its establishment. Similarly, it is difficult to maintain that the variables on 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 sizes of the coefficients. Although we may find the expected correlation between the average size of egg-production and rate of diffusion, it is not a very convincing result that the more involved a prefecture was in exporting egg cards, the lower its diffusion rate of F_1 hybrids. This rather peculiar finding is considered to be basically originated from the big difference in diffusion rates of East and West Japan.[33] More specifically, if one checks the in- and out-flows of silkworm eggs by prefectures, then the egg exporting prefecture is generally found to have a higher diffusion rate than <u>its</u> importing prefecture. These trades, however, were normally restricted to fairly short distances, viz. neighboring prefectures, and the diffusion rates in exporting prefectures of the East were not necessarily higher than those in exporting prefectures of the West, as the result reflecting the large discrepancy between East and West. Therefore, a clear-cut conclusion for the aggregate level of the whole of Japan is difficult to draw.[34]

Notwithstanding the prices of silkworm eggs and cocoons and the wages for sericulture workers are generally thought to have some influences on the diffusion speed of new varieties, price-related variables are excluded in our analysis. Since the price of a given variety was roughly the same throughout the country, although quality differences between varieties were reflected in the differences in prices. With regard to the wages, national data are unavailable, and the fragmentary information on them affirms almost no regional variations. These considerations preclude the possibilities of introducing those variables. Furthermore, one might conceivably substitute some other variables for those already chosen, such as the productivity of rice production or the planting area of mulberry trees instead of the proportion of summer-autumn rearings, or the production of raw-silk instead of the proportion 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 significant levels 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 geographical backgrounds, a few important characteristics on the relative position of prefectures should be pointed out from Figure 2. First, as already mentioned, the introduction of F_1 hybrids in each prefecture was almost always started from the spring rearings, and then

Fig. 2 Diffusion Rate of the F_1 Hybrid in 1918
(Spring vs. Summer-Autumn Rearings)



Source: Sangyo Torishimari Jimu Seiseki, 1918

gradually diffused to the summer-autumn rearings. Moreover the adoption rate of F_1 hybrids in the summer-autumn rearings was generally accelerated as that of spring rearings was increased. Secondly, there exists a distinct gap in diffusion rates between East and West Japan (the weighted average rate being 37.1 per cent and 66.7 per cent respectively). For instance, major sericulture prefectures in East Japan, such as Yamanashi (4.0 per cent), Chiba (10.8 per cent), Shizuoka (26.0 per cent), Nagano (28.5 per cent), etc., recorded very low rates of diffusion, whereas extremely high values were realized in the main rising-prefectures of the West, such as Kyoto (93.3 per cent), Tottori (89.5 per cent), Hyōgo (86.6 per cent), etc. Namely the diffusion of F_1 hybrids in the latter prefectures was almost completed as early as 1918, in contrast to quite slow starting of the former. Promoting factors for the diffusion have been extracted in our statistical analysis. Thirdly, the so-called traditional regions for sericulture (Ko-sanchi; Gunma, Saitama and Fukushima) displayed higher rates of diffusion than the so-called late coming 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 some existing technologies and in adopting new ones. This is an exactly similar phenomenon observed in the case of multi-ends reeling machines. These experiences of the shift of leading centers as to some specific technological innovations appear to suggest us a seesaw 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 as the most important factors to promote the diffusion of F_1 hybrids both the initiatives by large silk-reeling filatures and the educational and R&D activities for introducing them. These two factors shall be discussed in this section more concretely against the historical backgrounds.

It was the educational and R&D activities that promoted the transition from the age of "silkworm egg dealer's technology" to the age of "experimental station technology," and realized the rapid diffusion of F_1 hybrids by consolidating its foundation. With the enactment of Professional School Law in 1903, the Meiji government started also making its effort to establish the industrial school and vacational training center network. In the field of sericulture science as well, the higher education system and the industrial schools had been vastly expanded within a short period of time between late Meiji and early Taishō. For instance, in 1910 Ueda Sericulture Professional School was established, Sericulture Research and Training Center in Tokyo and Kyoto being converted into Sericulture Colleges in 1914, the branch of sericulture science being 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 on sericulture technology which was indispensable for new varieties to being broadly diffused over various prefectures. There is no doubt that the system of higher professional education was crucial in promoting the advanced researches on the genetic, hatching, incubation, etc. of silkworms and in transforming those findings to practical and profitable improvements. No one, however, cannot deny that encouraging and enlightening activities by the general sericultural education rendered the diffusion of various improvements all the more effective.

According to Nōrin gyōsei-shi [Administrative History of Agriculture and Forestry], as of 1919, there were 145 public schools offering more than 6 months' education for sericulture science (53 national and prefecture 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 prefecture institutions and 37 belonged to school associations. Meanwhile, intensive trainings were given also at prefectural egg-breeding stations to turn out a large number of sericultural experts.[36] Sanshi yōkan [Sericulture Handbook] provides the description of leading sericultural institutions, which suggests us the importance of the agro-sericulture schools founded by municipal school associations and other organizations. By 1923, as many as 25,731, or 17 per cent of the total 151,386 sericultural graduates were from agro-sericulture schools set up outside the national-prefecture system by various associations (viz. school, trade and agriculture associations), companies, private individuals, etc.[37] More than half of those graduates, 15,769 were graduated from the schools organized and run by municipal school associations. It is also difficult to diminish here the tremendous significance of research and educational activities sponsored by the public educational system at the central level. However, the key roles displayed by research and education in the development of the Japanese sericulture industry cannot be properly understood without reference to the dynamism due to the locally-based educational system by municipal, trade and agricultural associations, and other private organizations as well.

There is little doubt that the comprehensive educational efforts to diffuse new sericultural knowledge and techniques were major factor encouraging the rapid diffusion of F_1 hybrids. As pointed out earlier, this was resulted from the simple fact that the sizeable proportion of sericultural graduates found their works locally as instructors or technicians for trade and agricultural associations, or took the jobs connected with the sericultural industry in some ways. In doing so, they made outstanding contributions to the improvement and diffusion of sericulture technology on which they had obtained the 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 since the end of 19th century.[39] They were exactly the fruit of rather earlier establishment of the higher educational system for sericultural science, as shown in the typical example of College of Agricultural Science, Tokyo Imperial University. Many of those researches were of international caliber, and compared favourably with similar works conducted in France and Italy in those days. It should be also noted as a 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 those researches is beyond our scope of this paper, but at least two epoch-making innovations definitely accelerating the diffusion of F_1 hybrids should be mentioned here. They are the development of new techniques for artificial hatching and sexing method.

As known well, an artificial hatching is the practice of artificially giving a stimulus by various ways to hibernating eggs, causing them to hatch without overwintering. Different principles of stimulating eggs were theoretically known from an early date; for instance, the brushing method, acid treatment, the electric pressure method, oxygen treatment, etc. being typical ones. 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 a warm-water permeance method, and later it was perfected in 1917 as the so-called acid treatment method after cold-storage by T. Araki and E. Miura. The rapid diffusion of this new technique started in around 1919 from Aichi Prefecture to the whole country. Namely the artificial non-hibernating eggs in summer-autumn rearings were still 6 per cent in 1921, but by 1926 of five years later the proportion had grown to 72.4 per cent.[40] The development of artificial hatching techniques was of great importance for the diffusion of F_1 hybrids, especially of summer-autumn silkworms. Since they had been required the better management and more strict controls of silkworm-eggs in the beginning phase of rearing, and the artificial hatching 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 Agriculture Science, had already laid the theoretical basis for sex-identification through his research on silkworm genital glands, known well as Ishiwata Gland. In 1921 S. Karasawa developed the research to a practical sexing method applying the 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 prevailed previously, began to diffuse quite rapidly from Nagano Prefecture throughout Japan. To produce F_1 hybrids efficiently, sex-identification of parent silkworms was unavoidable, and the completion of such surer method contributed a lot to promoting the diffusion of F_1 hybrids. Now it should be noted that these two major improvements of artificial hatching and sex-identification were both developed and diffused from local silkworm-egg breeding stations.

Similarly, in other fields of sericulture technology, pioneering researches and practical improvements of their applications had been actively conducted by various educational and R&D institutions at different locations. Those informations and innovations were immediately introduced into production process by the direct producers, viz. egg-manufacturers and sericulture farmers, as first as the profitability of new techniques became apparent. There seemed to be two major routes through which such informations were 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, proceeded to the sericulture department of the prefectural and municipal governments; and from there the information was usually led to the local trade and agricultural associations where progressive manufacturers and veteran farmers could easily access it in their own network. This was almost certainly the main path by which technological information had travelled.

The second channel was the route of sericulture graduates from various institutions of different localities, who obtained new informations on sericulture technology through professional journals, manuals or lecture-notes and, after adapting them to fit local conditions and needs, guided actual producers to introduce them. These cases are observable on a fairly broad scale, as shown in the columns such as 'Questions & Answer,' 'Advices' or practical suggestions by technical experts of local egg-breeding stations in Journals of Sericulture Industry and of All Japan Raw-Silk Association. It is not too much to say that dominating the effectiveness of both channels of information in the long run was the education for the sericulture technology and industry.

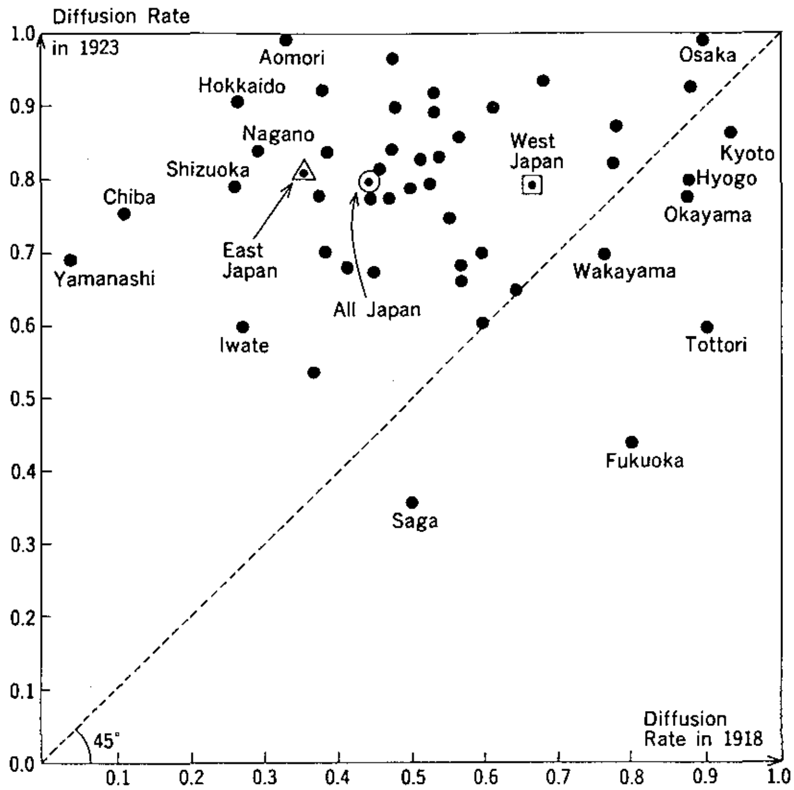
Strong influence of the second route on the diffusion of technology is demonstrated by the fact that practical publications on timely topics in sericulture technology had faithfully reflected the demand for technology newly introduced. In the case of the F_1 hybrid technology, practical and introductory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

2. Raw-Silk Demand as an Accelerating Factor

As the result of sericultural education and R&D activities stated so far, the diffusion of F_1 hybrids was promoted very rapidly between 1918 and 1923, as shown in Figure 3 of the movement for each prefecture. The most salient feature of Figure 3 is that the differentials existed in 1918 of F_1 hybrid's diffusion rates between East and West Japan, and also between the traditional and late-coming regions have completely disappeared by extensive progresses of the diffusion in conservative prefectures. Namely it was a result from the rapid diffusion of two different groups of prefectures in East Japan; the first was the significant progress of diffusion in the sericultural backward prefectures of a northern part such as Hokkaidō, Aomori and Iwate, and the second the steady penetration of F_1 hybrids into the major sericulture prefectures of Nagano, Yamanashi, Shizuoka and Chiba. These developments are distinctly depicted in Figure 3 in terms of the distance from the 45° line. Consequently the previous difference in diffusion rates between East and West Japan was totally eliminated, as 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, etc. are located far below the 45° line. That is, the diffusion rate of F_1 hybrids (the weighted average of all rearings) in those prefectures declined below the level recorded in 1918. This phenomenon appears to be a little paradoxical, but a careful examination on their data reveals us the real cause of such declines. In other words their decreases of the F_1

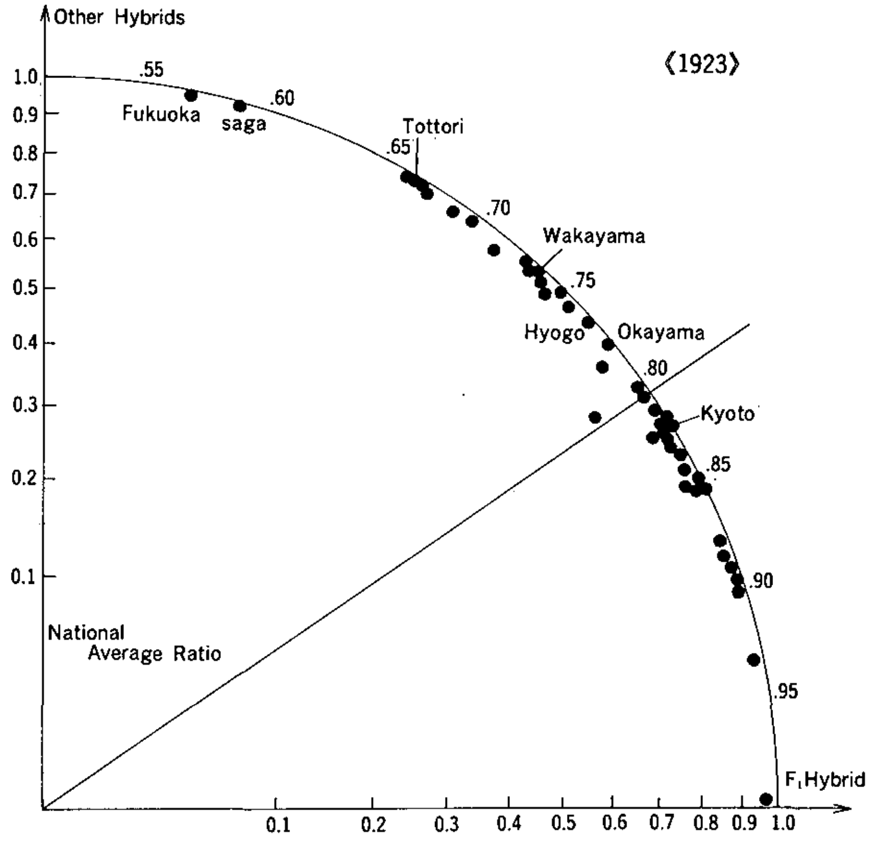
Fig. 3 Progress in Diffusion of the F_1 Hybrid (Prefecturewise, Total, from 1918 to 1923)



Source: Sangyo Torishimari Jimu Seiseki, 1918 and 1923.

hybrid diffusion rate were originated from very low rates of F_1 hybrids in the summer-autumn rearing, which were mainly owing to the problem of definition. Now the composition of the F_1 hybrid and other hybrids in summer-autumn rearings of each prefecture is plotted on the binomial probability paper of Figure 4 for the year 1923. This diagram shows the proportion of other hybrids in the above-mentioned prefectures being quite high, which is expressed as a cosine value on the vertical axis (the proportion of F_1 hybrids as a sine value on the horizontal axis). And the distance from the origin measures the total proportion of all hybrids, hence the residual implies the non-hybrid (i.e. fixed varieties) proportion. Accordingly Figure 4 tells us that as early as 1923 almost all summer-autumn rearings were already hybrid varieties in most prefectures.

Fig. 4 Relative Shares of the F_1 Hybrid and Other Hybrids
(Summer-Autumn Rearing in 1923)



Note: (1) Data are plotted on the binomial probability paper.
Source: Sangyo Torishimari Jimu Seiseki, 1923.

Furthermore, we have an additional useful information as to the production of hybrid varieties. Namely it was the so-called '3-way hybrid' that was a most popular crossing way around 1923 among 'other hybrid' varieties for summer-autumn rearings. As known well, the 3-way hybrid is the hybrid having the F_1 hybrid for one parent. Hence, although it was classified as a non-F_1 hybrid (i.e. one of other hybrids) in statistics, its hybridization technique definitely presupposed the cross breeding principle of the first filial hybrid. In those days more than 90 per cent of other hybrids was said to be the 3-way hybrid,[43] although orthodox F_1 hybrids such as a bi-bivoltine or uni-univoltine hybrid had prevailed soon after 1923 even in summer-autumn rearing varieties. Thus, if the 3-way hybrid is redefined as a F_1 hybrid in a enlarged sense because of the above reason, then by 1923, 98 per cent of spring rearing varieties and 96 per cent of summer-autumn rearing varieties were already of the F_1 hybrid. 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 the Japanese sericultural technology.

The dynamic leadership of large silk-reeling filatures was pointed out previously to be the most important factor to have realized the rapid diffusion of F_1 hybrids from the result of our probit analysis. Lastly a crucial background element should be mentioned to understand their strong leadership. That was the demand factor in the raw-silk market; (1) in 1910's the demand for raw-silk in the United States, Japan's largest export market, began to shift towards high-quality thread, and (2) this tendency was accelerated by the appearance of artificial silk, since coarse threads could not compete with the latter in prices. It, therefore, was the urgent problems for the Japanese raw-silk industry to grasp exactly the changes in the demand structure, and to remodel its production technology for adapting to new market conditions. In this respect the reeling filatures were best placed to realize and react to the necessity. It was in fact this moment that led to embark upon the production of silkworm eggs by themselves.

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

In the egg production market, the development of new varieties and their characteristics became more sensitive and exact in reflecting market conditions by the result of new entries of raw-silk producers who were most sensitive to changes in the raw-silk demand. What is more, these new comers were busy with developing new varieties to meet future trends of the demand. Thus their R&D activities contributed significantly to raise the technical level of egg production, and 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 the 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 kinds of various facts testify 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 got better workable in these markets as the result of reeling-filatures' entering into the egg production market. On the other hand, it must be pointed out that those 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 trades and found themselves forced to be shifted the manufacturers' risks. Such a tendency that farmers' interests were neglected had appeared especially after the early Shōwa when the special sub-contract system of cocoon trades became a widespread practice.[44] Where special subcontracts were involved, not only did silk-reeling filatures provide technical guidance, but in many instances they also supplied the credit to farmers, and this made the situation all the more vulnerable. Although these kinds of negative effects should be kept in mind, the contribution of silk-reeling manufacturers to the diffusion of F_1 hybrids must be highly appreciated. Since the leadership provided by them was the most important factor to realize the extremely rapid diffusion of the epochal variety.

IV. CONCLUDING REMARKS

So far various factors to have promoted the diffusion of the first filial hybrid silkworms were discussed in the context of historical backgrounds and the statistical analysis. Finally we summarize the conclusions obtained and draw their implications from a slightly broader perspective. In the early years of Taishō the F_1 hybrid silkworm was first developed, and immediately started its diffusion. As of 1918 stood at less than 50 per cent, the diffusion rates of F_1 hybrids in an extended sense, viz. including the 3-way hybrid, had promptly attained to 97 per cent by 1923 mere five years later. Regional differences of the rates among different sericultural regions had disappeared by this time, and silkworm varieties reared by sericulture farmers were almost without exception of F_1 hybrids. Namely the diffusion of the epoch-making variety F_1 hybrid was completed in less than ten years. This is an almost unparalleled example of rapid diffusions in the world's technological innovations. To be sure, when compared with hybridizations of other agricultural products, the control of silkworm crossings 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 favourable. But the exceptionally fast pace of diffusion cannot be attributed to technical causes alone. This process must be thought of as being governed rather thoroughly by more fundamental socio-economic factors.

To clarify this point, the probit analysis was adopted and applied to the cross-section data of 1918 for extracting the socio-economic accelerants of F_1 hybrid diffusion. It is worth remarking that two of the statistically examined factors 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 on F_1 hybrids. These factors explain enough as well, through checking the data of each prefecture, the reasons why there existed relatively large differences of the diffusion rates of F_1 hybrids among different sericultural regions. Our statistical analysis also suggests us as a somewhat generalized implication that the diffusion speed of new varieties was in fact dependent upon the degree of development of the regional markets.

Suppose the above reasonings for the rapid diffusion of F_1 hybrids are acceptable, we are led to facing the radically different evaluation on the promotors of diffusion activities from commonly held views. Namely the existing views that the diffusions of prewar agricultural technology were always realized by means of political subsidies in accordance with an authoritarian policy of Government seem to be totally incorrect, at least so long as concerned with the case of F_1 hybrid's diffusion. It was distinctly confirmed by not only our statistical findings but also close examination of individual historical facts. For instance, such evidences as long-standing attempts to improve indigenous varieties, sericulture instructors' circuits voluntarily provided by egg-manufacturers, sericultural training schools and lecture courses at their own expenses, etc. are crucial counter-examples to the prevailing views.

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 for 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 prefectural egg-breeding stations almost simultaneously with the establishment of a national station network. They also explain why not a small portion of parent-eggs for F_1 hybrids was developed by their own hands without depending entirely upon the available eggs supplied from the central station, and this resulted in giving great stimulus to the researches conducted at the national experiment stations. Similarly, with respect to sericultural education, it should be noted that, while public technical education system was successfully created in the beginning of the 20th century, privately organized industrial schools as well had 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 government's coercive diffusion policies alone without the support of competitive markets and vivid entrepreneurship of private producers.

The above understanding by no means discount the importance of roles taken by 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 roles for advancing the diffusion should be more appreciated when one takes into account the difficulties of egg-breeding techniques as a part of agriculture technology. Comparing with the diffusion of silk-reeling technology, our analysis on that of F_1 hybrids may point out two important common features in the diffusions of sericultural industry technologies. That is to say, in both cases the initiatives of large silk filatures and the demand factor in the raw-silk market were of fundamental importance in influencing the introducing-timing and diffusion-speed of new technologies.

On the other hand the agricultural technology, unlike the manufacturing technology, normally requires huge R&D investments for systematic development of technological innovations. In the case of silkworm hybridization, hence, the roles of public educational and R&D institutions were inevitably crucial. In other words the so-called competitive development or immitating innovation by individual firms, which characterizes the development of manufacturing technology, has its much smaller possibilities in the field of agriculture technology. Consequently the institutionally established route of technological information played a key part, and diffusion encouragers were often regarded as terminal organs of the diffusion hierarchical system rather than independent market forces. This is nevertheless not to imply that diffusion activities were always supervised by the authorities, or there existed no grass-rooted voluntary efforts for diffusing new sericultural technologies.

In any event, unique features of diffusion factors of agricultural and manufacturing technologies form a very interesting contrast and are in need of more various case-studies. It is lastly pointed out from a broader perspective that the extremely rapid diffusion of F_1 hybrids could be regarded as a product from the relatively homogeneous society of Japan. Since such a society is, as a rule, very competitive in joining new systems and efficient in transmitting various information. Although these features are necessary conditions for the efficient market mechanism, most of us Japanese are not forgetting as well the fragility of such a society as the tail of a coin in the anomalous situations which, for instance, was the basis for Japanese fascism during World War II.

NOTES

* This study is a part of the United Nations University project entitled "Technology Transfer, Transformation and Development: the Japanese Experience," which is promoted by the special committee of the Institute of Developing Economies, Tokyo. More precise and detailed discussion is available in the Japanese version as to the same subject. See Y. KIYOKAWA, "Sanpinshu no kairyō to fukyū-denpa: Ichidai kōzatsushu no bawai" [Improvements of Cocoon Varieties and Their Diffusion: A Study on the Experience of the First Filial Hybrid Silkworms], Keizai kenkyū, Vol.31, Nos.1 and 2, January and April 1980.

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 the F_1 hybrid silkworms, they completed the entire replacement of indigenous varieties 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 with his negative appraisal of the diffusion network organized by the Government.

3. The hybridization technology is considered here to belong to agricultural technology which is embodied in the growing process of organic system or organisms. Main characteristics of the diffusion in manufacturing technology are also analyzed for the case of greatly innovated silk-reeling technology, i.e. the multi-ends 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.

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] by R. Takashima, 1892. Dainippon san-shi [Sericulture History of All Japan] by E. Sano, 1898, dates this event to 1767 (pp.24-29).

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 on changes in popular varieties of cocoons.

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 Sericulture Industry, Part II] (mimeograph), Kyoto Sen'i Kōgei Daigaku, 1960, p.50.

9. Around 1890, there existed 325 training centers for sericulture 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 Fair, Trade Fair] and Hakuran-kai [Industrial Exhibition] were quite frequently held in various prefectures, and had played a very important role for 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).

12. Compared to the earlier legislation Silkworm Disease Prevention Law, etc., the new one 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 of producing and refrigerating silkworm eggs, tighter control of the markets for silkworm eggs and cocoons, the establishments of a federation of producers' cooperatives and a cocoon inspection committee to realize better selection and control of silkworm eggs, etc.

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.), Sanpin-shu ni kansuru chōsa [A Survey of Silkworm Varieties], Sanshi Dōgyōkumiai Chūōkai, 1921, pp.78-82.

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.

16. Calculated from Nōrinshō, Sanpin-shu 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 the national line varieties was between 20 and 30, the number of various local ones was more than two hundreds, say, around 1916, although the latter gradually decreased. See Nōrinshō, Sanpin-shu ni kansuru chōsa.

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

19. The Sericulture Industry Law, however, was revised in 1917, and a notification system was set up. This implies that after 1917, we cannot identify 'crossed' or 'hybrid' varieties by their names from ordinary fixed varieties, 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 both type cards of ordinary (commercial) and special (parent) silkworm eggs produced in each prefecture. 100 moths are converted into one card.

21. Calculated from Sanshi tōkei nenkan, 1930.

22. The parent eggs for F_1 hybrids were Nihon-nishiki, Ascoli, Szekzard, China No.7 and Blanc Pure in its production. The Origin of F_1 Hybrid, however, does not provide any further detailed information on the production of those parent eggs. Judging from the fact that

Sanpin-shu ni kansuru chōsa has not listed up those parent eggs as the strains distributed in 1914 by the central or local egg-breeding stations, it is quite plausible that Katakura Co. itself produced them with the cooperation of the Second Nagano Prefecture Station of Silkworm-Egg Breeding and/or the Matsumoto branch of the National Institute of Silkworm-Egg Production.

23. As for the origin of special sub-contract transactions, the names of Muroyama, San'in and Gunze Cos. should be also mentioned, since they had adopted earlier the similar guarantee system. After around the turn of the century, they introduced the so-called systems of credit transactions and conditioned weight transactions which were carried out in the form of sub-contracted rearings and price agreements based upon the objective appraisal on quality. In the case of Katakura, the special sub-contract system spread to other prefectures from Saga where county agricultural associations and sericulture cooperatives had prepared the groundwork.

24. See Sanshu seizō o nasu kaisha, kumiai sonotano dantai ni kansuru chōsa [Survey on Companies, Cooperatives 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 by its strict pure line separation. But it should be pointed out that, as those eggs were isolated and produced from traditional fixed varieties, they naturally had some continuities 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 in Katakura Co. corresponded to National European Nos.3 and 6 respectively. For more details, see H. Hiratsuka (ed.), Kindai sanpin-shu ikushu kiroku [Breeding Records on Modern Silkworm Varieties], Sanshi Kagaku Research Institute, 1961 and T. Yokoyama, "A History of the Development of Sericulture Technology (10)," in Sanshi kagaku to gijutsu [Agriculture Science and Technology], August 1965.

26. Concerning the significance of the prefectural units in the diffusion process, the reader is referred to the author's paper, "Silk Reeling Technology." For details on the probit analysis, any standard textbook of statistics with a special reference to the medical science may be consulted, as it is not touched upon here to save the 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.

28. The rate of special sub-contract transactions is measured in terms of cocoons as the amount of cocoons reared under the sub-contracting system divided by the total production of cocoons in each prefecture.

29. The total number of sericulture-science major graduates 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 in 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 on Sericultural Institutions and Their Expenditure, 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, Noshōmu tōkei hyō, dai 35-ji [Statistical Yearbook on Agriculture and Commerce, the 35th] for x_5. For other four variables x_1, x_2, x_7 and x_8, all of the data are adapted from Noshōmu tōkei hyō (the 34th, 35th).

31. For a reference, the estimate by the regression analysis is given as follows:

$$y = 0.534 + \underset{(1.34)}{0.042x_1} - \underset{(-1.41)}{0.041x_2} + \underset{(2.94)}{0.079x_3} + \underset{(2.11)}{0.051x_4}$$

$$+ \underset{(2.76)}{0.070x_5} + \underset{(1.57)}{0.041x_6} + \underset{(2.22)}{0.056x_7} - \underset{(-1.76)}{0.045x_8}$$

$$R^{*2} = 0.486$$

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

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

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

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

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. Specifically the contribution of local schools at the initial stage was remarkable. It is also noted that 68 per cent of total sericultural graduates had studied the sericulture science more than 3 years. This attests to the high standard of sericulture instructors and technicians in Japan.

38. In 1925 the number of sericulture instructors amounted to 10,430, 80 per cent of whom were seasonal itinerant advisers. Later, as the special sub-contract practice spread over, the number of technical experts employed in silk filatures grew rapidly. See Yōzan ni kansuru chōsa.

39. For more details, see Nihon sanshigyō-shi [History of Researches on Sericulture Science], Vol.5. A brief history on sericultural research is also found in T. Yokoyama, "A History of the Development of Sericulture Technology: (6), (7) and (8)," Sanshi kagaku to gijutsu, April, May and July 1965 respectively.

40. Calculated from Yōzan ni kansuru chōsa.

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

42. Sericulture-related publications were quite active particularly in Nagano, Gunma, Aichi, and also in Fukushima, Saitama, Gifu and Hiroshima. Some noticeable books and pamphlets were published as well from Date and Ueda Egg-Production Cos., the egg-breeding stations in Aomori and Saitama, and Silkworm-Egg Trade Association of Yamanashi. 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.

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 per cent of 'other hybrids' were still of this type.

44. See for instance, H. Akashi, Kindai sanshigyō hattatsu-shi [A History of the Development of the Modern Sericulture

Industry], pp.403-06. The author was a former official of the Ministry of Agriculture and Forestry, and his view is well worth consulting for this reason.