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TECHNOLOGY TRANSFER AND AGRICULTURAL DEVELOPMENT*

V. W. Ruttan and Yujiro Hayami**

## I. Introduction

The "technology factor," in either its embodied or disembodied form, is increasingly recognized as a major source of differences in productivity and welfare over time and among nations.1/ Yet technical change is one of the more difficult products for a country in the early stages of economic development to produce. In agriculture the initial success of the "green revolution" has resulted in renewed interest in the economic and institutional considerations involved in international technology transfer.2/

The international diffusion of agricultural technology is not new. The classical studies by Sauer and Vavilov and the more recent cytogenetic studies of plant origins indicate that the international and intercontinental diffusion of cultivated plants, domestic animals, hand tools, and husbandry practices was a major source of productivity growth in prehistory and in the classical civilizations.3/ It is well known that the transfer of new crops (potatoes, maize, tobacco, and others) from the new continents to Europe after the discovery of America had a dramatic impact on European agriculture. The technological bases for the staple exports of many developing countries -- cocoa in West Africa and rubber in Southeast Asia, for example, -- occurred as a result of the international diffusion of crop varieties.

Before agricultural research and extension were institutionalized, this diffusion took place as a by-product of travel, exploration, and communication undertaken primarily for other purposes.4/ Over a long gestation period -- several decades and even centuries -- exotic plants, animals, equipment, and husbandry techniques were gradually introduced and adapted to local conditions. In the 19th century the international diffusion process became more highly institutionalized. National governments established agencies to deliberately seek out and introduce exotic crop varieties and animal breeds.5/ Colonial governments and the great trading companies operating under their protection sought to introduce crops with export potential into new areas of cultivation. These efforts have, over time, had a substantial impact on the location of staple production and on international trading patterns in crop and animal products.

The enormous agricultural productivity differences among countries, combined with the success of earlier diffusion efforts, have often been interpreted to imply that more effective diffusion of known agricultural technology among countries could represent an efficient source of economic growth in agricultural productivity and production in the less developed countries. This perspective imposed a "naive diffusion" or "extension bias" to much of the national and international aid efforts for agricultural development that emerged after World War II. In reviewing the agricultural development efforts of the 1950's and early 1960's, Albert Moseman emphasized that "this 'extension bias' met with only limited success because of the paucity of applicable indigenous technology and the general unsuitability of U.S. temperate zone materials and practices to tropical agricultural conditions."6/

In this paper we draw, from earlier research on the diffusion of culture and technology, insights that can contribute to a more adequate understanding of the processes involved in the international transfer of agricultural technology and the impact of such transfer on the location of agricultural production and international trade in agricultural commodities. This analysis leads us to place major emphasis on the emergence of national experiment station capacity for adaptive research and development as a critical element in the international transfer or "naturalization" of agricultural technology.

## II. Diffusion Models and International Technology Transfer

There are multiple traditions of research on diffusion processes: in anthropology, economics, geography, sociology, and other disciplines. Each tradition has evolved a somewhat different model of the diffusion process. Aside from differences in terminology, real differences among these models exist because they are concerned with different aspects of diffusion phenomena. The main focus of sociologists and geographers has been on the impact of communication (or interaction) and sociocultural resistance to innovation on the pattern of diffusion over time and across space.7/ The models of economists have focused on how economic variables, such as the profitability of innovation and the asset position of firms, influence the rate of diffusion.8/

The models have, with a few exceptions, only limited relevance for the international transfer of technology in agriculture. They have typically been designed to describe or analyze diffusion within a particular area over time. The attributes of the technology and the attributes of potential adopters are taken as given.9/ While these models are highly useful for the purposes for which they were designed, the assumption of ready availability and of direct transferability of the technology represents a critical limitation in utilizing them to understand the process of international diffusion in situations where ecological variations and differences in factor endowments among countries inhibit the direct transfer of agricultural technology.

The study by Griliches of the diffusion of hybrid corn represents a rare attempt to incorporate the mechanism of local adaptation into a diffusion model.[10] The study is of relevance because the diffusion of hybrid corn among geographic areas, through the development of locally adapted varieties, is similar to our view of the process of international technology transfer in agriculture. "Hybrid corn was the invention of a method of inventing, a method of breeding superior corn for specific locations. It was not a single invention immediately available everywhere. The actual breeding of adaptable hybrids had to be done separately for each area. Hence, besides the differences in the rate of adoption of hybrids by farmers . . . we have also to explain the lag in the development of adaptable hybrids for specific areas . . ."[11]

The procedure employed by Griliches was to summarize the diffusion path for each hybrid corn maturity area by fitting an S-shaped logistic trend function to data on the percentage of corn area planted with hybrid seed in each maturity area. The logistic trend function is described by three parameters -- an origin, a slope, and a ceiling. Griliches interpreted his results as indicating that differences among regions in the rate (slope) and level (ceiling) of acceptance are both functions of the profitability of a shift from open-polinated to hybrid corn. Variations in these two parameters among regions are thus explained in terms of farmer's profit-seeking behavior. In this respect Griliches' model is similar to other diffusion models employed by economists.

What makes the Griliches's study unique, and relevant to the problem of international technology transfer, is that he incorporated into his model the behavior of public research institutions and private agricultural supply firms which make locally adapted hybrid seeds available to farmers. He attempted to explain variations in the date of origin, or of commercial availability, of hybrid corn by the size and density of the hybrid seed market estimated from the size and density of corn production.

From this analysis Griliches derived the conclusion that both the efforts of the agricultural experiment stations and the commercial seed companies were guided by the expected return to research, development, and marketing costs. It is one of the great merits of the Griliches' model that it incorporates the mechanism of local adaptation in the interregional transfer of agricultural technology. This mechanism is based on the behavior of public research institutions and private agricultural supply firms. Modification of the model is needed, however, in applying it to the study of international technology transfer.

In the United States, there exists a large stock of scientific and technical manpower, a well-structured federal-state experiment station network, and vigorous entrepreneurship in private farm supply firms. The mechanism for inducing the research and development necessary for local adaptation of technology functions efficiently. When these conditions are not met, even if the expected pay-off from the transfer of a particular technology is potentially very high, the supply of adaptive research may be very inelastic. The problem of facilitating international technology transfer as an instrument for agricultural development is, therefore, how to institutionalize an elastic supply of adaptive research and development. The most serious constraints on the international transfer of agricultural technology are: (a) limited experiment station capacity in the case of biological technology and (b) limited industrial capacity in the case of mechanical technology. The inelastic supply of scientific and technical manpower represents a critical limiting factor in both cases.

## III. Phases of International Technology Transfer

It seems useful to distinguish three phases of international technology transfer: (a) material transfer, (b) design transfer, and (c) capacity transfer.

The first phase is characterized by the simple transfer or import of new materials such as seed, plants, animals, machines, and techniques associated with these materials. Local adaptation is not conducted in an orderly and systematic fashion. The "naturalization" of plants and animals tends to occur primarily as a result of trial and error by farmers.

In the second phase the transfer of technology is made primarily through the transfer of certain designs (blue prints, formula, books, etc.). During this period exotic materials are imported in order to copy their designs rather than for their own use. New plants and animals are subject to orderly tests and are propagated through systematic multiplication. Machines imported in the previous phase start to be produced domestically with only slight modifications in design.

In the third phase technology transfer occurs primarily through the transfer of scientific knowledge and capacity. The effect is to create the capacity for the production of locally adapted technology according to the "proto-type" technology existing abroad. Increasingly plant and animal varieties are bred locally to adapt them to local ecological conditions. The design of imported machinery is modified in order to meet climatic and soil requirements and factor endowments of the economy. An important element in the process of capacity transfer is the migration of agricultural scientists.

In spite of advances in communications, diffusion of the concepts and craft of agricultural science, and of science and culture generally, depends heavily on extended personal contact and association.12/ The transfer of scientists is often of critical importance in easing the constraints on the supply of scientific and technical manpower in the less developed countries. Much of the institutional development effort of the international aid agencies can appropriately be viewed, and evaluated, against the objective of speeding entrance of the LDC's into the capacity transfer phase.

The three phases of international transfer of agricultural technology outlined above are tested against two cases: the development and diffusion of sugarcane varieties, and the transfer of the tractor to the USSR and Japan.

Development of sugarcane varieties

Robert Evenson's study on the development of sugarcane varieties is of interest because it represents a major example of the international transmission of biological technology in agriculture, and because the process has evolved from a simple transfer of plants to the phase of capacity transfer.13/

Evenson identified four stages of development in sugarcane varieties: Stage I -- Natural Selection (Wild Canes). The cane plant reproduces asexually. Until the late 1800's relatively few wild or native varieties were commercially produced. These varieties apparently were the result of natural asexual reproduction. They were transmitted between countries, but the transmission was extremely slow. For example the "Bourbon" cane, the major stage I cane in the 19th century, was not introduced to the British West Indies until 1785, almost a hundred years after it was a commercial cane in Madagascar.

Stage II -- Sexual Reproduction (Noble Canes). The discovery of the fertility of the sugarcane plant in 1887 independently in Barbados and in Java established the basis for the breeding of new varieties. Under proper conditions the cane plant can be induced to flower and produce seedlings. Each new seedling is then a potential new variety since it can be reproduced asexually. The early man-made varieties were produced using the existing commercial 80-chromosome cane species Saccharum Officinarum as parent varieties. Between 1900 and 1920 numerous varieties resulted from this effort. These varieties were transmitted widely over the world from experiment stations in Java, India, Barbados, British Guiana, and Hawaii. Many were distributed to other countries and, when introduced, appeared to be definitely superior to the native varieties. Only simple tests and demonstrations were required, if any, for recipient countries to propagate these varieties. In many cases, however, these new varieties were susceptible to diseases and their yield advantages were lost.

Stage III -- Interspecific Hybridization (Nobilization). The experiment station in Java (Proefstation Oost Java, P.O.J.) achieved a major advance in cane breeding by introducing the species Saccharum Spontaneum into their breeding programs after 1915. Through a series of crosses and back crosses new interspecific hybrids were developed that incorporated the hardiness and disease resistance of this non-commercial species. Later, the station at

Coimbatore, India, developed a series of tri-hybrid canes by introducing a third species, Saccharum Barberi. This resulted in the development of new varieties in India that were specifically adapted to local climate, soil, and disease conditions. The stage III varieties were disease resistant and high-yielding, notably those from Java and India. They were transferred to every producing country in the world. While this international transmission was widespread, it did not occur easily. The existence of research and extension capacity in the recipient countries was an important factor in determining the rate of diffusion of the new cane varieties.

Stage IV -- Location Specific Breeding. The Coimbatore, India, station set the stage for modern breeding activity. More than 100 experiment stations are now in existence. In most cases they are pursuing programs which involve systematic selfing and crossing of parent varieties suitable to the specific soil, climate disease, and economic conditions of relatively small regions. Very little international transmission of varieties is now taking place, as most regions are producing sugar from cane varieties developed at a regional or natural experiment station.

It appears reasonable to interpret sugarcane variety transfers during stages I and IV as clearly belonging to the material transfer and the capacity transfer stages. Stage II appears to be a transition from the material transfer to the design transfer, and stage III a transition from the design transfer to the capacity transfer. Significant implications of this sequence are: (a) the increasingly important role which the experiment station has played in developing and "naturalizing" sugarcane varieties, and (b) the sequence running from initial international diffusion of superior varieties to the international diffusion of the capacity to "invent" location specific varieties superior to the "naturalized" varieties.

Tractorization in Russia and Japan

One of the dramatic examples of the transfer of mechanical technology in agriculture was the Soviet adoption of American mechanical technology, particularly the tractor, during the 1924-33 decade. Also of interest is the transfer of small-scale mechanical equipment to Japan since the mid-1950's. In both cases the experiment station occupied a relatively minor role, in contrast to the major role of the experiment station in the transfer of biological technology. An important element in the transfer of machine technology in agriculture in both the USSR and Japan was the domestic manufacturing capacity.

The tractor occupied an important role, for both ideological and practical reasons, in the development of agriculture in the USSR. The transfer of American machine technology to the USSR has been documented by Dalrymple.[14] The three phases in the evolution of technology transfer can be observed.

Material transfer -- Importation: In 1924 there were only about 1,000 tractors in operation in the USSR. By 1934 the number had increased to over 200,000. Approximately half of this total was imported, mostly from the United States. After 1931 imports dropped sharply.

Design transfer -- Domestic Production: Tractor production in the USSR rose from seventeen in 1924 to close to 5,000 in 1929. By 1933 production exceeded 50,000 and in 1934 approximated 100,000 units. This development was also heavily dependent upon the contributions of U.S. technology. The early Russian tractors were direct copies of U.S. models, primarily Fordson and International Harvester machines. The Russian tractor manufacturing plants were designed by American firms and constructed under the direction of U.S. construction engineers who had been associated with similar developments in Detroit and Chicago. Russian technical teams visited Detroit and Chicago, and American foremen were imported to train the workers and help run the new plants.

> "Thus by the early to middle 1930's the Russians were producing reproductions of their American tractors, in plants designed by Americans, built under American supervision, and initially operated under American supervision. In this way . . . the Russians were able to acquire quickly and with very little effort the technical knowledge of tractor production which had taken years to develop in this country."15/

Capacity transfer: Beginning in 1922 the Russians also began to import to the USSR American farmers and American farm management specialists to advise in the organization of large scale mechanized farming units and to instruct in the use of tractors. American influence in the adaptation of mechanized production to the economic and technical conditions of Russian agriculture was, however, less pervasive than it was in tractor importation and production. From the beginning the productive use of the new equipment was hampered by improper use and inadequate maintenance.[16]

A remarkable aspect in the Soviet adoption of U.S. machine technology is that it has continued to center on large scale tractors. There is still no indication that machine size has been reduced to be more consistent with factor endowments of the economy. This seems to be explainable in terms of the Russian motivation to mechanize agriculture. The Soviet efforts of farm mechanization were inseparably related to Stalin's policy of heavy industrialization.

It was designed to procure an agricultural surplus for industrialization (by means of compulsory delivery) while breaking the economic power of the peasantry. In terms of this goal, the development of efficient small-scale machinery, consistent with the peasant or family farm mode of production, was considered undesirable. Big tractors were a means of forcing peasants to adapt to the socialist mode of production.

Given the factor endowments in Russia, however, it was inevitable that this large-scale mechanization has led to a significant malallocation of resources in Soviet agriculture.[17] Institutional constraints apparently limited the ability of the Soviet farm machinery industry in developing the capacity to design and produce farm machinery consistent with the factor endowments of the USSR. As a result, the capacity transfer stage was aborted.

"Mini-tractorization", an introduction of the small-scale tractors of less than ten horsepower in post-War Japan, represents a clear contrast to this Russian experience. Before World War II, mechanization in Japan was restricted to irrigation, drainage, and post-harvesting operations; tractors were introduced only on an experimental scale.[18] The number of hand tractors on farms rose sharply from virtually nonexistence in the 1940's to 89,000 in 1955, to 517,000 in 1960, and to 2,500,000 in 1965.

This post-war spurt of tractorization in Japanese agriculture may partly be explained by the increased income of farm households due to the land reform and by the relatively high food prices in the early post-war period. Higher incomes, and higher returns to labor, induced farmers to substitute tractor power for manual labor in crop production.

Supply pressure from the machinery industry was also important. From the beginning of modern economic growth until the end of World War II the Japanese machinery industry depended heavily on military procurement. When this favored market was eliminated, after World War II, the industry was left with significant idle capacity, especially of engineering and technical manpower, and was forced to divert part of its capacity to agriculture.[19] Domestic production of hand tractors increased from only 60 in 1945, to 34,000 in 1955, to 305,000 in 1960, and to 437,000 in 1965.

Under the strong supply pressure of the machinery industry Japan quickly bypassed the material transfer-importation phase, and advanced to the capacity transfer phase. Small-scale tractors were imported from abroad primarily for purposes of design transfer. The first tractors manufactured in Japan (called "power cultivators") were subject to several defects including heavy body weights relative to the power generation and inadequate design for paddy field operation.[20] These defects were soon corrected. Two major developments which brought about the rapid growth of tractorization in the mid-1950's were (a) an increase in the power of the "power cultivators" from less than five h.p. to the range of five to ten h.p., which permitted a depth of cultivation comparable to the depth of horse plowing, and (b) the development of small hand tractors in the low h.p. range with interchangeable attachments. These modifications made it possible to replace draft animals completely by small-scale tractors in paddy field operations.

Extremely rapid progress in the "mini-tractorization" has puzzled many Japanese agricultural economists. Some have questioned its efficiency and have developed a hypothesis of "over-mechanization" based on demonstration effects and other psychological elements.[21] Tsuchiya's recent study, however, indicates that increased utilization of tractors can be explained by the efforts of farmers to reduce production costs in response to rising wage rates relative to the price of agricultural machines and equipment without invoking such factors.[22]

In contrast to the Russian experience the Japan experience involved the tailoring of tractors, and other farm machinery, to the size of the individual production unit.

## IV. Technology Transfer and Agricultural Trade

Successful technology transfer frequently introduces substantial disequilibrium in factor and product markets. The effects are not confined to domestic markets, but frequently spill over into the international economic system. Ceteris paribus, the transfer of technology, implies a reduction in the "technology gap" among areas and among countries. Comparative advantage for a certain commodity in a nation which initially developed the superior technology for the commodity may be lost as the technology is transferred abroad. When the international technology gap is closed, the comparative advantage and the trade matrix will be determined primarily by relative factor endowments.

In order to understand the "feed-back" of international technology transfer on trade relationships the "product cycle model" developed by Raymond Vernon is suggestive.23/ According to Vernon both the new consumer goods (e.g., automatic washer) and producer goods of labor-saving characteristics (e.g., fork-lift) tend to be developed initially in the United States because size of the market, with a large number of high income consumers, and the high labor cost in the United States provide a favorable environment for product innovations. In spite of higher labor costs in the United States Vernon suggests that initial production capacity for new consumer and producer goods will tend to be located in the United States because of the dynamic interrelationships between innovative effort and the market response to new products during the early phases of technological innovation, product design, and market development. For the initial producers of a new product for the United States market these considerations are "far stronger than relative factor-cost and transport considerations" that have been emphasized in traditional trade and location analysis.

Following the period of product innovation and modification a certain degree of product standardization takes place. As the need for flexibility declines, technical possibilities for achieving economies of scale open up. Initially the manufacturing plants tend to be located within the United States because it is the only market large enough to exploit the scale economies. Thus, from the product innovation to the early stage of standardized production, the United States remains as a dominant exporter of the new products. As the non-U.S. market expands and the product standardization is completed, the production capacity is built in other advanced countries and finally the international firms begin to service the third-country markets or even the home market from overseas locations characterized by lower labor costs.

"If economies of scale are being fully exploited, the principle differences between any two locations are likely to be labor costs. Accordingly, it may prove wise for the international firm to begin servicing third-country markets from the new location. And if labor costs differences are large enough to offset transport costs, then exports back to the United States may become a possibility as well."24/

The Vernon model is designed to analyze the innovation-investment-trade sequences in industrial production. In agriculture, however, it is not the standardization of the product or the production process which facilitates the transfer of new production capacity from the developed to less developed countries. Rather, it is the establishment of an agricultural experiment station system in the recipient countries with capacity to conduct the research and development necessary to adapt foreign materials and designs for local adoption. Yet, once such a system is established and the production potentials implicit in foreign technology are being fully exploited, comparative advantages tend to be determined by differences in factor endowments among countries. The initial advantage of an innovator may be lost as the new technology is transferred among countries as a result of local adaptation and development.

The case of sugarcane examined in the previous section provides an example illustrating the sequence following innovation and technology transfer. The Java station (P.O.J.) was the leading generator of new varieties from 1900 to 1930. During most of this period Java experienced an increasing relative advantage over other sugar producing countries. The "technology gap" became widest around 1930. After 1930 the decline in world demand and the widespread diffusion of the capacity to breed superior "location specific" varieties in other sugar producing areas (except Cuba) led to a decline in sugar exports from Java.

A more dramatic example may be seen in the process of transferring rice production technology from Japan to Taiwan and Korea during the inter-war period.[25] The agricultural productivity growth of Japan from the beginning of modern economic growth following the Meiji Restoration (1868) to World War I was supported by the propagation of the better farmers' techniques screened and tailored by experiment station workers following the modern agricultural science tradition of Germany. The initial phase of rice yield increase was caused by the diffusion of superior varieties selected by veteran farmers (Rōnō) within the western part of Japan, which included the most advanced regions (Kinki and Northern Kyushu).[26] These superior varieties in the West provided the proto-type for farmers and experiment station workers in the East in developing improved varieties for their ecologies. The experiment stations in their early days contributed to agricultural productivity growth by exploiting indigenous potential rather than by supplying new potential.

By adequately screening and tailoring veteran farmers' varieties and practices, Japan was able to obtain substantial increases in agricultural productivity by exploiting the indigenous technological potential. Through the diffusion of these techniques, first among the western prefectures and later among the eastern prefectures, domestic rice production was able to supply about 95 percent of the domestic consumption during the period of the big spurt in industrialization between the Russo-Japanese War (1904-05) and World War I. The impact of the indigenous technological potential on productivity gradually declined, however, as it became widely diffused.

The exploitation of indigenous potential and the lag in scientific research in supplying new potential, when confronted with the expansion of demand due to World War I, resulted in a serious rice shortage and forced the rice price to rise to an unprecedented level. This caused serious disruption in urban areas, culminating in the Kome Sodo (Rice Riot) in 1918.

The reaction of the government to the Rice Riot was to organize programs to import rice from the overseas territories of Korea and Taiwan. In order to create a rice surplus to export to Japan, short-run exploitation policies were adopted. In Korea this involved importing sorghum (milo) from Manchuria and forcing farmers to substitute this lower quality grain for rice in domestic consumption. A similar squeeze was also practiced in Taiwan, forcing Taiwanese farmers to substitute sweet potatoes for rice in their diet. This was enforced by a squeeze on real income through taxation and by government monopoly sales of such commodities as liquor, tobacco, and salt.

The longer-run program was to introduce development programs designed to increase the yield and output of rice in the two colonial territories. Under the program titled Sanmai Zoshoku Keikaku (Rice Production Development Program), the Japanese government invested in irrigation and water control and in research and extension in order to develop and diffuse high yielding Japanese rice varieties adapted to the local ecology of Korea and Taiwan. Success of this effort created a tremendous rice surplus which flooded into the Japanese market. As shown in Table 1, within the 20 years from 1915 to 1935 net imports of rice from Korea to Japan rose from 170 to 1,212 thousand metric tons per year, and net imports from Taiwan rose from 113 to 705 thousand metric tons. As the result of the inflow of colonial rice the net import of rice rose from 5 to 20 percent of the domestic production.

Table 1. -- Production, import and available supply of rice in Japan, 1890-1935*

| Year | Supply $Q = Z + K$ | Production $Z$ | Net Import: Total $K$ | Net Import: Korea $K_k$ | Net Import: Taiwan $K_k$ | Production | Net Import: Total $k = K/Z$ | Net Import: Korea $k_k=K_k/Z$ | Net Import: Taiwan $k_f=K_f/Z$ |
|---|---|---|---|---|---|---|---|---|---|
| | (1000 m. tons) | | | | | (percent) | | | |
| 1890 | 5813 | 5861 | -48 | | | 100 | -0.8 | | |
| 1895 | 5700 | 5651 | 49 | | | 100 | 0.9 | | |
| 1900 | 6578 | 6372 | 206 | | | 100 | 3.2 | | |
| 1905 | 7539 | 6943 | 596 | | | 100 | 8.6 | | |
| 1910 | 7923 | 7588 | 335 | | | 100 | 4.4 | | |
| 1915 | 8692 | 8286 | 406 | 170 | 113 | 100 | 4.9 | 2.1 | 1.4 |
| 1920 | 9720 | 8838 | 882 | 360 | 132 | 100 | 10.0 | 4.1 | 1.5 |
| 1925 | 10043 | 8700 | 1343 | 640 | 278 | 100 | 15.4 | 7.3 | 3.2 |
| 1930 | 10483 | 9070 | 1413 | 974 | 389 | 100 | 15.6 | 10.7 | 4.3 |
| 1935 | 11290 | 9414 | 1876 | 1212 | 705 | 100 | 19.9 | 12.9 | 7.5 |

* Five years' averages centering the years shown. Rice in brown (husked but not polished) rice basis.

Source: Yujiro Hayami and V. W. Ruttan, "Korean Rice, Taiwan Rice, and Japanese Agricultural Stagnation: An Economic Consequence of Colonialism," Quarterly Journal of Economics, Vol. 84 (November 1970), pp. 566-582.

The success of the government program in developing Korea and Taiwan as major suppliers of rice to Japan had a major impact on rice prices and production in Japan. Such large scale imports of rice, a commodity characterized by a relatively inelastic demand schedule, significantly lowered the price and discouraged the production of rice in Japan. A deterioration in the price and in the terms of trade for rice during this period was the logical consequence of the policies designed to increase imports from Korea and Taiwan.[27/]

Both the motivation and consequence of the colonial rice development program are illustrated in Figure 1 which compares the trends of rice yield per hectare in Japan, Taiwan, and Korea. Yield per hectare in Korea and Taiwan began to take off in the 1920's when the growth decelerated in Japan. This reflects the process we have discussed so far: (a) The Japanese government launched the colonial rice development program when pressed by the food problem arising from the deceleration in the growth of rice yield per hectare in Japan and rising food demand from a growing nonagricultural population. (b) The success of the program in raising rice production and productivity in the two colonies permitted large scale imports of rice from these territories, which in turn depressed the price and further discouraged the production of rice in Japan.

The success of the colonial rice development program was a mixed blessing for Japan. It depressed the price and the income of farmers and contributed to serious social disorders in the agricultural sector. The so-called military

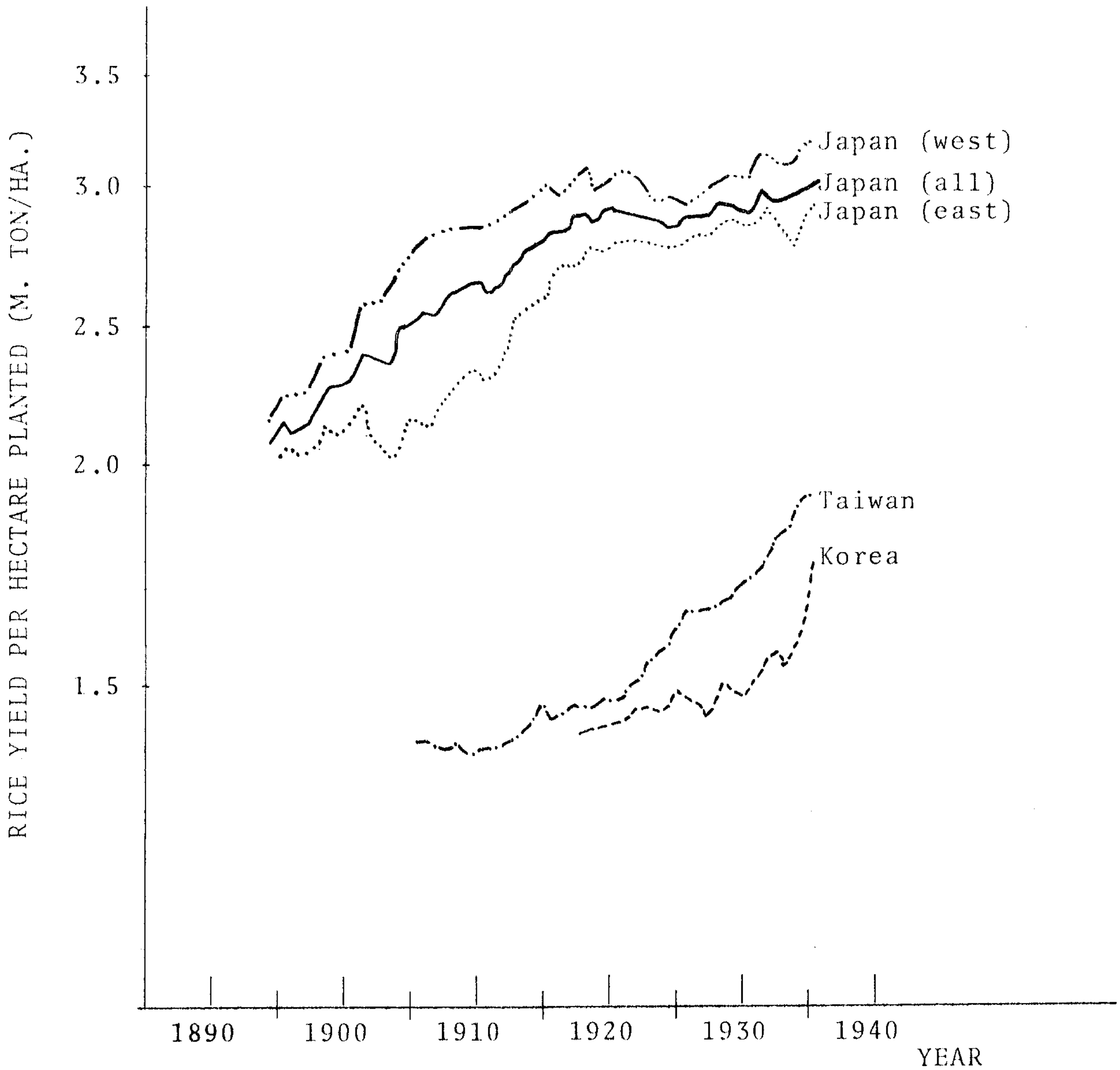


Figure 1. Rice yields per hectare planted for Japan, Taiwan and Korea, five-year moving average, 1895-1935.

Eastern prefectures: Aomori, Iwate, Miyagi, Akita, Yamagata, Fukushima, Ibaragi, Tochigi, Gunma, Chiba, Saitama, Tokyo, Kanagawa, Niigata, Nagano, Yamanashi, Shizuoka, Aichi.

Western prefectures: Toyama, Ishikawa, Fukui, Gifu, Mie, Shiga, Kyoto, Osaka, Hyogo, Nara, Wakayama, Tottori, Shimane, Okayama, Hiroshima, Yamaguchi, Tokushima, Kagawa, Ehime, Kochi, Fukuoka, Saga, Nagasaki, Kumamoto, Oita, Miyazaki, Kagoshima.

Source: Nobufumi Kayo, (ed.), Nihon Nogyo Kiso Tokei (Basic Agricultural Statistics of Japan), (Tokyo: Norin Suisangyo Seisansei Kojo Kaigi, 1958); Taiwan Government-General, Taiwan Nogyo Nenpo (Yearbook of Taiwan Agriculture), (Taipei), various issues; Korea Government-General, Nogyo Tokeihyo (Agricultural Statistics), (Seoul), various issues.

reformists made this social uneasiness and disorder among farmers the springboard for the invasion of Manchuria in 1931 and the other military adventures which followed. The policy decision concerning the rice supply after the Rice Riot in 1918 had thus not only economic but vast social and political implications.

Why did the economic effects of colonial development policy fail, in Japan, to produce the "classical" results associated with the importation of cheap grain into England from colonial areas and other areas of new settlement in the 19th Century? The answer seems, at least in part, to be associated with the different structure of agriculture and the different pattern of industrial development in the two countries when the policies of dependence on overseas sources of food supply was initiated.

The inflow of cheap grain to England following the repeal of the Corn Laws in 1846 was accompanied by the continuing absorption of labor into the industrial sector and a transformation of the agricultural sector away from grain production and toward a more intensive system of livestock agriculture. The transformation was facilitated by rising incomes in the industrial sector which stimulated the demand for the products of an animal agriculture.

A number of obstacles impeded the achievement of a similar agricultural transformation in Japan in response to rising imports and declining prices of grain during the interwar period. Japanese agriculture was rigidly locked into a sophisticated labor intensive system of crop production, highly dependent on irrigation and fertilizer as leading inputs. There was not a fully adequate basis, in either agricultural research or industrial infrastructure, to make a rapid transformation from grain production to a more diversified agricultural system. Furthermore, the rise in imports of grain was not accompanied, in Japan, by rapid growth in the demand for labor by the industrial sector. The demand for labor in the industrial sector slackened after 1920 as a result of (a) contraction of world demand for the products of Japanese industry after World War I, (b) contraction of domestic demand due to the deflation policy adopted to permit a return to the gold standard at a prewar parity, and (c) the adoption of an industrial rationalization policy in an attempt to stay competitive in world markets. This policy placed major emphasis on attempts to increase productivity and to save labor through more capital intensive methods of production. Finally, income levels in the urban industrial sector of the Japanese economy remained too low to create a large increase in the demand for the products of a more diversified agriculture.

## V. Technology Transfer and the Green Revolution

The most dramatic example of agricultural technology transfer during the last several decades has involved the recent development and diffusion of new high-yielding varieties (HYV's) of rice, wheat, and maize in the tropics (Table II).[28] We will analyze this so-called "green revolution" in the light of the theory and history of international technology transfer that we have reviewed so far.

### Organizations for the transfer of technology[29]

Of particular significance is the fact that the development of the HYV's represents a process of agricultural technology transfer from the temperate zone to tropical and sub-tropical zones through the transfer of scientific knowledge and research capacity. Long before the 1960's the HYV's had been developed in Japan, the United States, and other developed countries in the temperate zone. The direct transfer of these superior varieties had, however, been inhibited by differences in ecological conditions. Technological transfer was delayed by lack of experiment station capacity to develop HYV's comparable to the "proto-type" varieties which existed in the temperate zone.[29] It is particularly significant that this new capacity was directed to improvement in yield of the staple food crops consumed domestically, rather than to the "enclave" tropical export commodities which had received primary attention under colonial administration.

Table II. Estimated area planted in high-yielding varieties (HYV) of rice and wheat in West, South, and Southeast Asia

| | Rice | | | | Wheat | | | |
|---|---|---|---|---|---|---|---|---|
| | 1966/67 | 1967/68 | 1968/69 | 1969/70 | 1966/67 | 1967/68 | 1968/69 | 1969/70 |
| | ---Thousand acres--- | | | | | | | |
| Turkey | | | | | 1 | 420 | 1,430 | 1,540 |
| Iran | | | | | | | 25 | 222 |
| Afghanistan | | | | | 5 | 54 | 302 | 361 |
| Nepal | | | 105 | 123 | 16 | 61 | 133 | 186 |
| West Pakistan | | 10 | 761 | 1,239 | 250 | 2,365 | 5,900 | 7,000 |
| East Pakistan | 1 | 166 | 382 | 652 | | | 20 | NA |
| India | 2,195 | 4,408 | 6,625 | 10,800 | 1,270 | 7,270 | 11,844 | 15,100 |
| Ceylon | | | 17 | 65 | | | | |
| Burma | | 8 | 412 | 356 | | | | |
| Malaysia | 104 | 157 | 225 | 316 | | | | |
| Laos | 1 | 3 | 5 | 5 | | | | |
| Vietman | | 1 | 100 | 498 | | | | |
| Indonesia | | | 488 | 1,850 | | | | |
| Philippines | 204 | 1,733 | 2,500 | 3,346 | | | | |
| Total | 2,505 | 6,486 | 11,620 | 19,250 | 1,542 | 10,170 | 19,654 | 24,409 |

Source: Dana G. Dalrymple, Imports and Plantings of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations, Foreign Economic Development Service, U.S. Department of Agriculture, in cooperation with Agency for International Development (Washington, D. C., Jan., 1971), pp. 35,36.

Within the tropics the diffusion of the new cereals technology from Mexico (wheat) and the Philippines (rice) was characterized by an initial material-transfer phase. The initial impact of the diffusion of the new varieties on grain production in Pakistan, India, Malaysia, Turkey, Mexico, and other countries involved the direct transfer of seed of the new varieties from Mexico and the Philippines; and of fertilizer, insecticides, and fungicides from Japan, the United States, and Western Europe. In other countries, such as Thailand, the impact was delayed until the design and capacity transfer phases could be achieved, in order to maintain the quality characteristics of the Thai varieties which are important in the export market for Thai rice. In the countries that benefited initially from material transfer, there has been a rapid movement to develop the local experiment station capacity that will permit them to move to the design-transfer and capacity-transfer stages in the development of ecologically adapted varieties. There is also, in many countries, a move toward the development of a domestic fertilizer and agricultural chemical industry based primarily on developed-country designs.30/

The adaptive research that led to the development of HYV's was primarily conducted at a new set of international agricultural research centers. These centers are typically supported by major U.S. Foundations. They are staffed by international teams of scientists of various agricultural science disciplines and by in-service trainees, and coordinated by a common orientation to produce major breakthroughs in the yield potentials of certain staple cereals. Establishment of these research-training centers can be considered as an institutional innovation facilitating the transfer of an "ecology-bound" location specific agricultural technology from temperate zone developed countries to tropical zone developing countries. It is useful, therefore, to review the evolution of these institutions, particularly the International Center for Corn and Wheat Improvement (CIMMYT) in Mexico and the International Rice Research Institute (IRRI) in the Philippines. Similar international centers have recently been established in Colombia (CIAT) and Nigeria (IITA). The new international centers are also exerting a major impact on the organization of national research systems.

CIMMYT and IRRI do not, of course, represent completely new concepts of research organization. Commodity-centered research institutes established in the tropics under British, Dutch, and Belgian Colonial auspices have been responsible for substantial productivity gains in the production of tropical export crops. The new international institutes represent an extension and further evolution of an already established institutional pattern.31/

The Rockefeller Foundation Agricultural Sciences program, which eventually led to the establishment of CIMMYT and IRRI, was initiated in 1943 with the establishment of the Office of Special Studies (Oficina de Estuidos Especiales) in the Mexican Ministry of Agriculture.32/ Field research programs were first initiated with wheat and corn. The program later expanded to include field beans, potatoes, sorghum, vegetable crops, and animal sciences. A common pattern of staffing was followed for each commodity program. A. U.S. specialist was brought in as each commodity program was initiated. Each specialist assembled a staff of young Mexican college graduates who were trained in research methods and practices as part of the research program, rather than through a formal program of graduate studies.

In retrospect, the staffing program adopted by the Foundation and centered around a project leader for each commodity did have one major limitation. In situations where progress depended on the solution to a complex set of interrelated problems in varietal improvement and crop-production practices, the commodity specialist was rarely able to bring to bear the range of disciplinary knowledge and technical skill needed to achieve progress in crop production. This can be illustrated by comparing the relative progress of the wheat and corn programs. The wheat program achieved technical success earlier and its impact on yield per hectare and on total wheat production has been greater than for the other commodity programs. New wheat varieties were being distributed to farmers by the fall of 1948. By 1956 the production impact was sufficient to make Mexico independent of imported wheat.

The rapid progress of the wheat program was clearly related to the special competence of the early leaders of the wheat program in the fields of plant pathology and genetics and the fact that stem rust was a dominant factor limiting wheat yields. It was also facilitated by effective institutional linkages with related programs in the U.S. and elsewhere.33/

Improvement in corn yields occurred much more slowly. In addition to a more complex set of biological factors, the institutional considerations involved in seed multiplication, distribution, and diffusion were more difficult. In retrospect, it appears that success would have been more rapid if initial efforts had been directed to the development of high yielding synthetic varieties rather than double-cross hybrids.

In situations where the technical, production, and organizational problems were relatively complex, requiring contributions from a broad spectrum of biological and social scientists, the staffing pattern worked out during the early years of the Mexican program was not entirely consistent with rapid progress in the solution of research and production problems. In these more complex situations a multidisciplinary team approach emerged as a more appropriate strategy than the simple commodity specialist approach of the early years.

A major source of strength in the success of the Rockefeller Foundation program in Mexico was its economical use of the scarce professional manpower available in Mexico both at the beginning and throughout the program. The shortage of professional manpower and of indigenous educational resources was conducive to the development of an internship system which intimately linked professional education with investigation.

By 1963 agricultural science had been successfully institutionalized in Mexico. On December 30, 1960, the Office of Special Studies was dissolved and merged into a new National Institute of Agricultural Research (INIA) under Mexican direction. The Rockefeller Foundation program staff in Mexico was reorganized into a new International Center for Corn and Wheat Improvement (CIMMYT). The shift of the national program to Mexican management involved serious emotional strain. One of the more difficult problems faced by the Rockefeller Foundation staff in making the transition was the recognition that they would occupy a marginal role in a program which they had developed. In technical assistance programs, the disengagement phase is often more difficult than the institutional-building phase.

The significance of the disengagement is that it symbolized Mexican success of agricultural science as a career service in which men could enter with confidence that their contributions would be rewarded both in money and in professional recognition. It is also significant that on May 14, 1963, advanced degrees in the agricultural sciences were conferred for the first time in Mexico. Mexico's new capacity to produce trained manpower in the agricultural sciences is developing in response to the demand for scientific manpower generated by the success of the initial thrust of the technical revolution in Mexican agriculture.

The establishment of the International Rice Research Institute (IRRI) in the Philippines in 1962 represents a second major landmark in the evolution of the agricultural science program of the Rockefeller Foundation. The IRRI was jointly financed by the Ford and Rockefeller Foundations and established as an international research and training institute rather than as a component of a national ministry of agriculture. It was staffed by an international team of scientists representing eight different nationalities. Recognition of the complexity of the problem of achieving higher yield potentials and the multi-disciplinary competence that would be required to solve the biological problems posed thereby and to achieve rapid increases in total national and regional output were recognized and carefully structured into the staffing plan.[34] An intensive program of seminars and research program reviews was initiated to focus the efforts of the diverse multinational and multidisciplinary team on a common set of objectives and to achieve the complementarity among the several disciplines necessary to invent, develop, and diffuse a new high-productivity rice technology.

The location of the IRRI in Los Banos, adjacent to the University of the Philippines College of Agriculture (UPCA), made professional resources available to the IRRI that had not been available in Mexico. The UPCA had already developed relatively strong departments in several fields of agricultural science. Joint appointments of IRRI staff to the UP graduate school strengthened the graduate research capacity of the UPCA. This arrangement permitted many of the IRRI trainees to work toward M.S. degrees under the direction of an IRRI staff member while simultaneously engaging in a highly complementary research "internship" at the Institute.

Within six years after the initiation of the research program at the IRRI, a series of new rice varieties with yield potentials roughly double that of the varieties that were previously available to farmers in most areas of Southeast Asia had been developed. By the late 1960's progress had proceeded far enough to have a measurable impact on aggregate production.[35]

The significance of the international institute experience, both in Latin America and in Asia, goes well beyond the impact of the new wheat, corn, and rice technology in at least two respects. The most important contribution was the evolution of an institutional pattern for the organization of scientific resources which can be replicated for a wide variety of crops and localities with a reasonable probability of success. It is now possible to organize a multidisciplinary team of biological, physical, and social scientists capable of adapting any new biological and chemical technology for crop production to local growing conditions, and to make this technology available to farmers in a form that they are capable of accepting within the relatively short period of five to ten years.

According to Rasmussen, the "systems approach," in which the multidisciplinary teams of scientists cooperate to solve a problem, characterizes modern development in agricultural technology in the United States and other developed countries, in contrast to the traditional "component approach," in which individual inventors and scientists work sporadically according to their inspiration and insight.36/ The International Institute experience clearly demonstrates the possibility of transmitting the "systems approach" to the less developed countries.

A second contribution of the new international centers was the evolution of a technique for establishing a set of linkages with national and local education and research centers. This technique includes activities such as exchanges of staff, professional conferences, support of graduate and post-graduate training, personal consultations, and exchange of genetic materials. An institutional infrastructure that is capable, at least in part, of offsetting the inability to fully exploit the economies of scale, which characterize the larger national research systems, is evolving. This communication function of the internationalinstitutes is particularly important for the experiment stations located in the smaller countries where the development of a broad-based national research system is limited.

The internationalresearch training institute approach clearly represents an effective institutional innovation in the process of technology transfer. It has been particularly effective in situations characterized by a supply of indigenous scientific manpower and experiment station capacity that is inadequate to achieve effective realization of the scale economies inherent in research and development activities, and in fostering the development of regional research and training infrastructure which can contribute to the support of self-sustaining progress of agricultural technology. The next stage in this development must be the strengthening of national research and production education systems.37/ In a few countries this may mean the building of new national research systems. In most countries the task is much more complex. It involves the transformation of existing national research systems into productive sources of new technical knowledge.38/

Feedback effects of technology transfer and agricultural readjustments

It is almost inevitable that the dramatic transfer of technology which generated the green revolution would result in substantial stress on several institutions in the relatively underdeveloped economies of the topics where these changes are occurring.

Immediate bottlenecks are emerging in the capacity of the marketing system to handle the sharp increase in the marketable surplus. In the spring of 1968 Northern India found the existing marketing facilities inadequate for handling the increased output of wheat. Substantial amounts of grain were stored in schools or even left uncovered on the ground. In the Philippines lack of artificial drying facilities for rice harvested during the monsoon season has represented a bottleneck for expansion of double cropping of rice.

Channels of input and credit supply represent equally urgent constraints. In order to exploit the production potential of HYV's, fertilizer and other technical inputs must be supplied at the right time and in the right places. Farmers require credit in order to meet the increased cash outlay for the procurement of larger amounts of technical inputs. The existing credit and input market facilities have in some areas represented serious constraints on the progress of the green revolution.

These bottlenecks impede the realization of production potential of new technology. At the same time, however, they can be powerful sources of forward and backward linkages, in Hirschman's sense, in transmitting the impact of the new technology in agricultural production to other sectors of the economy.39/ The marketing bottleneck in the green revolution, for example, implies that the pay-off to investment in agricultural marketing is increased by the development of HYV's. If investment is induced by the increase in the pay-off, not only the marketing bottleneck will be eased but also additional nonfarm employment and income will be created.

If this mechanism functions properly, the new seed-fertilizer technology can realize its production potential and at the same time contribute to sustained growth in the nonagricultural sector of the economy. A secular consequence of rapid growth in agricultural output, relative to demand, is a downward shift in the aggregate cost and supply schedules for food staples. The effect is to transfer at least part of the gain in agricultural productivity from farmers to other sectors of the economy. When the aggregate supply of commodities which are characterized by inelastic demand, such as staple cereals, shifts downward, the decline in the prices may exceed the increase in the output, resulting in a decline in the income of farmers.40/

Technological change may also contribute to the widening income disparities among farmers. The relative income position of farmers who have no access to new technology due, for example, to the lack of irrigation facilities will worsen as the aggregate supply schedule shifts to the right. Declining prices and widening income disparity among farm producers may contributeto significant social tension and disruption in rural areas and major political instability at the national level.41/

These problems can be magnified in the international dimension. As traditional food deficit countries, such as The Philippines and Pakistan, shift from a grain importing to a grain exporting status and other countries, such as India and Indonesia, reduce the gap between production and utilization, substantial price disruption is likely in international markets. This would have severe repercussions on the foreign exchange earnings of food exporting countries, such as Thailand and Burma, and may result in significant reduction in the trade among countries in Asia.42/

The problem of converting current or potential food surpluses into a basis for sustained economic growth poses an extremely difficult problem for most countries of South and Southeast Asia during the next decade. The continuing decline of export opportunities and prices sharply reduces the opportunity to use surplus production to earn the foreign exchange needed to finance domestic development. Furthermore, the relatively large share of the population engaged in agricultural production and the slow (absolute) growth in nonfarm employment opportunities limits the economic gains that can be realized by using the surpluses primarily to support employment in the urban-industrial sectors, unless the transfer of surpluses is also accompanied by lower food prices.

Thus, if Japan and other developed countries do not adopt less protectionist policies with respect to their domestic agriculture, the economies of Southeast Asia are likely to face difficulties during the 1970's similar to those faced by the Japanese economy during the interwar period. The main difference is that the downward pressure on rice prices in these countries will come from increased supplies generated from internal rather than colonial sources.

The Japanese experience during the interwar period indicates that for the economic and social conditions of Asian agriculture it is extremely difficult to achieve structural adjustments comparable to those associated with the agricultural transformation in 19th century England. Unique patterns and processes of agricultural readjustments have to be discovered which are feasible for Asian conditions.

In contrast to the interwar period, aggregate world trade is expanding even though trade in food grains is contracting. Demand for feed grains and luxury food items are increasing rapidly. Maize in Thailand, asparagus and mushrooms in Taiwan represent examples of success in diverting resources from food grains to the production of the commodities for which world demand is undergoing more rapid expansion. It is suggestive that these successes were achieved in the traditional food surplus countries in Asia.

Another possibility is that as the reduced real cost and prices of food staples become reflected in wage rates they will result in downward shifts in the cost schedule for rubber, copra, plywood, and other tropical export commodities. To the extent that this counteracts the competition from synthetics and temperate zone agricultural products, the traditional export crop sector could again emerge as a leading sector in some tropical economies.

Whether these possibilities materialize depends, to a large extent, on the efficient allocation of agricultural research. Research is essential to discover and develop new profitable crops. The competitive position of traditional export crops must be maintained and reinforced by continuous improvements in technology. It is unlikely that countries in South and Southeast Asia can attain a successful agricultural transformation if technical progress brought about by the transfer of scientific knowledge and capacity is limited to the food cereal sector.

Critical to the efficient reallocation of resources, including research resources, is an efficient system of prices which accurately reflect changes in the demand and supply of outputs and inputs in the economy. If the governments of South and Southeast Asian countries divert substantial resources to maintain the present level of food cereal prices, the result will be malallocation of resources not only by farmers but also by agricultural scientists and agricultural supply firms. In consequence, the cost schedules of these surplus commodities will continue to shift downward relatively more rapidly; and the disequilibrium will be widened.

The developing countries cannot afford to duplicate the costly experience of the developed countries during the past two decades. The developed countries can bear the heavy direct costs and the waste of resources resulting from high agricultural price supports. In most developed countries agriculture generates less than ten percent of the national income. Price supports have been effective in easing the social tensions within the rural population. Most developing countries do not have either the administrative capacity or the resources to pursue high price support policies. Though painful, they will be forced to follow a route towards agricultural readjustments under efficient price signals. Price support programs can be used for stabilization purposes and as a guide to efficient resource use decisions if they are not distorted by overly ambitious income transfer objectives.43/

The problem of attaining an efficient reallocation of agricultural resources while maintaining sufficient equity in welfare among the rural population and between the rural and urban sectors will require extreme skill. It may generate more social tension than the political structures of many developing countries maybe able to absorb.

## VI. Summary and Implications

There are three major implications of the material presented in this paper on which we would like to place particular emphasis.

(a) The international transfer of agricultural technology involves the domestication of exotic plants and genetic materials to local ecologies and modification in the design and use of machines, chemicals, and cultivation techniques to be consistent with the factor endowments and relative factor prices in recipient countries. Failure of a nation to institutionalize domestic research capacity can result in serious impediments to effective international technology transfer. A major challenge for the developing countries is to develop the scientific and institutional capacity to design and adapt location specific agricultural technology to the resource endowments and economic environments in which the new agricultural technology is to be employed.

(b) Most developing countries are too small to develop a fully articulated viable agricultural research system. National agricultural research systems of all except the very largest countries are likely to be most effective if they are linked into an international research network which provides for effective scientific communication and the transfer of genetic materials, research methods, and scientific personnel. A new set of international agricultural research centers is now emerging which, if developed effectively, can provide the institutional basis for much more effective international diffusion of agricultural technology than has existed in the past.

(c) Effective international diffusion of agricultural technology can be expected to have substantial "feedback" effects on trade relationships and domestic prices through the operation of international commodity markets. Our review of the experience of a number of countries over the past century leads us to place greater emphasis on the creation of the capacity of agricultural science to create new and more effective production alternatives than on attempts to achieve a high degree of organization or management of world commodity markets.

Notes

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9/ This has been of concern to some of the leaders in the field of diffusion research. Hägerstrand, in summarizing his work, points out: "In the models attention was directed to the processes of change, to how the distribution of $g_n$ generates the distribution of $g_{n+1}$. The location of the starting point of the diffusion process was stated among the assumptions. However, we observe that when agricultural indicators and agricultural elements are involved, the same small areas within the region seem repeatedly to be the starting points for new innovation. . . . The origin of such centers is a problem in itself." Hägerstrand, op. cit., p. 293.

10/ Zvi Griliches, op.cit., 1957. The Griliches study is also of interest because subsequent discussions helped to clarify the role of economic and sociocultural factors in the diffusion process. See Lowell Brandner and Murray A. Straus, "Congruence versus Profitability in the Diffusion of Hybrid Sorghum," Rural Sociology, Vol. 24 (December 1959), pp. 381-383; Zvi Griliches, "Congruence versus Profitability: A False Dichotomy," Rural Sociology, Vol. 25 (September 1960), pp. 354-356; Everett M. Rogers and A. Eugene Havens, "Adoption of Hybrid Corn: A Comment," Rural Sociology, Vol. 27 (September 1962), pp. 328-330; Zvi Griliches, "Profitability versus Interaction: Another False Dichotomy," Rural Sociology, Vol. 27 (September 1962), pp. 327-330; Jarvis M. Babcock, "Adoption of Hybrid Corn: A Comment," Rural Sociology, Vol. 27 (September 1962), pp. 332-338; Gerald E. Klonglan and E. Walter Coward, Jr., "The Concept of Symbolic Adoption: A Suggested Interpretation," Rural Sociology, Vol. 35 (March 1970), pp. 77-83; Kenneth J.

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15/ Dalrymple, op. cit., 1964, p. 201.

16/ " . . . rates of scrapping are about twice as high as those in the United States . . . utilization to full capacity on huge farm units leads a more rapid wearing out of machines. In recent years the supply of new tractors to agriculture in the Soviet Union has been larger than in the United States; yet the total tractor fleet in the USSR increases only slowly. The Soviet ractor figures confirm that the use of men and machines in the USSR is machine-centered, as would be expected in a low-income economy. In the United States and estern Europe, with high and rapidly rising per-capita incomes, the use of machines centers around the use of manpower, aiming at maximizing the efficiency of labor committed to agricultural production by means, among other things, of some excess capacity in tractors and other heavy machines (p. 289-290): Folke Dovring, "Soviet Farm Mechanization in Perspective," Slavic Review, Vol. 25 (June 1966), p. 287-302.

17/ "By tailoring agriculture to big tractors, it has forced agriculture into an absurd, bimodal structure of farm sizes, i.e., exceedingly large state and colletive farms and tiny plot farms, a bimodal structure based on big tractors and many hoes. Both types are highly inefficient. . . . Suppose these plot farms were increased to no more than 10 acres and suppose small hand (garden-type) tractors and complementary machines and equipment were made available; total agricultural production in the Soviet Union would rise sharply . . . " (p. 123): Theodore W. Schultz, Transforming Traditional Agriculture (New Haven: Yale University Press, 1964), p. 123.

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24/ pp. 198-200.

25/ The following review is based on material presented in greater detail in Yujiro Hayami and V.W. Ruttan, "Korean Rice, Taiwan Rice, and Japanese Agricultural Stagnation: An Economic Consequence of Colonialism," The Quarterly Journal of Economics, Vol. 84 (November 1970), pp. 562-589; and Yujiro Hayami, "Elements of Induced Innovation: A Historical Perspective for the Green Revolution," Explorations in Economic History (forthcoming, 1971); and R.E. Evenson, J.P. Houck, Jr., and V.W. Ruttan, op.cit.

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29/ This section draws heavily on Vernon W. Ruttan, "The International Institute Approach," Agents of Change: Professionals in Developing Countries, Guy Benveniste and Warren F. Tichman (eds.) (New York: Praeger, 1969), pp. 220-228.

Peter R. Jennings, "Plant Type as a Rice Breeding Objective," Crop Science, Vol. 4 (January-February, 1964), pp. 13-15; E. A. Jackson, "Tropical Rice: The Quest for High Yield," Agricultural Science Review, Vol. 4 (Fourth Quarter 1966), pp. 21-26. The Jenning article represents the classic statement of the new crop breeding strategy focusing on models of biologically efficient plant types.

30/ The role of material transfers on the initial impact of the new grain varieties on production has been documented in a series of country papers prepared for the 1969 spring review at the US AID. The material presented in the country papers have been summarized in two papers: Wayne A. Schutjer and E. Walter Coward, Jr., "Planning Agricultural Development--The Matter of Priorities . Journal of Developing Areas (forthcoming 1971); and E. Walter Coward, Jr. and Wayne A. Schutjer, "The Green Revolution: Initiating and Sustaining Change," paper presented at the Annual Meeting of the Rural Sociological Society, 1970. The contribution of material inputs is also emphasized in Wayne Schutjer and Dale Weigle, "The Contribution of Foreign Assistance to Agricultural Development," American Journal of Agricultural Economics, Vol. 51 (November 1969), pp. 788-797. The results obtained by Schutjer and Coward in the AJAE article do not reflect the significance of capacity transfer. It was only after the new production functions characterized by a higher response to material inputs were developed that the material transfer became profitable.

31/ " . . . commodity research stations were established by the British in tropical Africa and later turned into regional institutes. A Cocoa Research Institute was launched in Ghana in 1938 followed by the Oil Palm Research Station in Nigeria in 1939. Beginning in 1957, these national commodity research stations were regionalized and the West African Cocoa Research Institute (Sierra Leone), West African Oil Palm Research Institute (Nigeria), West African Maize Research Institute (Nigeria), the West African Institute for Social and Economic Research (Nigeria), plus five other West African Research Institutes were established. As West African Nations Gained independence, starting with Ghana in 1957, problems emerged which led to the breakup of all the West African institutes. . . . the British acted with impressive foresight in developing biological research stations in Africa . . . ." Carl K. Eicher, "Regional Programming for Rural Development in Tropical Africa: Implications for AID," paper presented at a conference on African Development from a Regional Perspective (Warrenton, Virginia, November 14-16, 1969), mimeo. For a more detailed treatment of colonial research in the areas under British administration see Charles Jeffries, A Review of Colonial Research, 1940-1960 (London: H.M.S.O., 1964). For a comment on the inadequacy of the colonial research effort see Green and Hymer, op. cit.

32/ The decision to initiate the program was made following the report in 1941 of a survey team consisting of Richard Bradfield (Professor of Agronomy and Head of the Department of Agronomy, Cornell University), Paul C. Mangelsdorf (Professor of Plant Genetics and Economic Botany, Harvard University), and E. C. Stakman (Professor of Plant Pathology and Head of the Department of Plant Pathology, University of Minnesota). The team was sent to Mexico as a result of a request to the Rockefeller Foundation from the Mexican Ministry of Agriculture following a visit to Mexico by Vice-President Henry Wallace. For further background see Arthur T. Mosher, Technical Cooperation in Latin-America Agriculture (Chicago: University of Chicago Press, 1957), pp. 100-126; Stakman, Bradfield, and Mangelsdorf, op.cit.; Delbert T. Myren, "The Rockefeller Foundation Program in Corn and Wheat in Mexico," Subsistence Agriculture and Economic Development, Clifton R. Wharton, Jr., (ed.) (Chicago: Aldine Publishing Co., 1969), pp. 438-452.

33/ "The initial varieties raised were selected from hybrid materials furnished by McFadden of the USDA staff working at the Texas Agricultural Experiment Station. Borlaug also continued to draw heavily on the materials available to him from Kenya, Australia, and the United States, with particularly close ties to Dr. B. B. Bayles who was in charge of the USDA program on wheat improvement. Subsequently, Dr. O. A. Vogel of the USDA staff at Pullman, Washington, contributed significantly by furnishing hybrids involving the short-strawed, high-yielding Norin selection which had been introduced from Japan in 1947 by Dr. S. C. Salmon of the USDA. This strong tie to the experience and materials in the U.S. and elsewhere was an important factor in the steady growth of the wheat project, together with the fact that the short-strawed, high-yielding, disease-resistent, fertilizer-responsive varieties were particularly well-suited for the irrigated areas in Northwest Mexico," A. H. Moseman in a letter, January 3, 1969.

34/ Stakman, Bradfield, and Mangelsdorf, op.cit., p. 298. See also Randolph Barker, "The Contribution of the International Rice Research Institute to Asian Agricultural Development," Change in Agriculture, A. H. Bunting (ed.) (London: Gerald Duckworth and Co., Ltd., 1970), pp. 207-218.

35/ These developments have been widely reported in the popular press typically in a highly exaggerated form. For a more careful assessment see Randolph Barker, "Economic Aspects of New High-Yielding Varieties of Rice: IRRI Report," Agricultural Revolution in Southeast Asia: Impact on Grain Production and Trade (Vol. I) (New York: The Asia Society, Inc., 1970), pp. 29-53. Also Dana G. Dalrymple, op.cit., 1971.

36/ Wayne D. Rasmussen, "Advances in American Agriculture: The Mechanical Tomato Harvester as a Case Study," Technology and Culture, Vol. 9 (October 1968), pp. 531-543.

37/ Delane E. Welsch and Ernest W. Sprague, "Technical and Economic Constraints on Grain Production in Southeast Asia," Agricultural Revolution in Southeast Asia: Impact on Grain Production and Trade (Vol. I), op.cit., pp. 13-28.

38/ See, for example, the discussion of the agricultural research system in Brazil in Edward Schuh, The Agricultural Development of Brazil (New York: Praeger, 1970), pp. 227-240. In spite of substantial investment in agricultural research the impact on productivity has been small. According to Schuh, much of the productivity increase that has been observed in Brazilian agriculture "comes from a change in product mix, and not from an increase in yields or productivity from the same crop" (p. 184).

39/ A. O. Hirschman, The Strategy of Economic Development (New Haven; Yale University Press, 1958).

40/ This process has been documented for U.S. agriculture by Willard W. Cochrane, Farm Prices, Myth and Reality (Minneapolis; University of Minnesota Press, 1958).

41/ Francine R. Frankel, "India's New Strategy of Agricultural Development: Political Costs of Agrarian Modernization The Journal of Asian Studies, Vol. 28 (August 1969), pp. 693-700; Guy J. Pauker, "Political Consequences of Rural Development Programs in Indonesia," Pacific Affairs, Vol. 41 (Fall 1968), pp. 386-402.

42/ The trade implications of the green revolution are discussed in a series of papers presented at the Honolulu meeting of the SEADAG Rural Development Seminar. See Trade and Price Policy Implications of the New Cereals Technology (New York: The Asia Society, 1970). See also Randolph Barker, ed., Rice Policy Conference: Country Papers (Manila: International Rice Research Institute, May 1971 (preliminary)).

43/ "In their drive for greater social equity, or perhaps a more eqalitarian society, many developing nations have forgotten that prices and wages have the role of allocating resources as well as producing income. . . . This means that developing countries with weak administrative structures should not generally attempt to achieve equity, or social goals, through price and wage manipulations....A classic example of this occurred in India in the early 1960's. In an effort to hold food prices to 'fair' levels for urban consumers as food production lagged, farm prices were depressed by government-requisitioning procedures; ...The effort to achieve an equity goal—namely, low food prices for urban consumers — acted to dampen down food production at the very time that an expansion was desperately needed." Willard W. Cochrane, The World Food Problem; A Guardedly Optimistic View (New York: Crowell, 1969), pp. 287-288. More recently a number of developing nations, the Philippines and Pakistan in particular, have been unable to maintain announced price support levels. In general price support actions may have made a greater contribution to price instability than to stability in most developing economies.