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ELEMENTS OF INDUCED INNOVATION:
A HISTORICAL PERSPECTIVE OF THE GREEN REVOLUTION

By

Yujiro Hayami

Department of Agricultural Economics

University of Minnesota
Institute of Agriculture
St. Paul, Minnesota 55108

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The dramatic appearance and propagation of high yielding varieties (HYV) of rice and wheat in Asia since the mid-1960's have been heralded widely as a "green revolution". It is generally regarded as a highly successful demonstration of how the systematic application of scientific methods can be employed to create a new technology capable of transforming the traditional agriculture of the great mass of peasants in Asia.

Of particular significance is the fact that the green revolution demonstrates the process of international transmission of "ecology-bound" agricultural technology from developed countries to less developed countries through the transfer of the scientific knowledge embodied in scientists rather than through the direct transfer of known technology. It reinforces the growing recognition that advanced agricultural technology (e.g., HYV's) existing in the temperate zone developed countries is not transplantable to tropical and sub-tropical regions without the adaptive research of high caliber scientists. The HYV's developed by coordinated research by international teams of scientists have been spreading rapidly within countries and across national boundaries (Table 1). As a result it appears possible that agriculture in a number of countries in the tropics is now in the initial phase of a transition from an economic backwater to a major contributor to overall development [1/].

In this essay we attempt to analyze the market forces that induced such a dramatic development of the HYV's. Results of this study suggest that

Table 1. Estimated area planted in high yielding varieties (HYV) of rice in West, South, and Southeast Asia.

	Rice			Wheat		
	1966/67	1967/68	1968/69	1966/67	1967/68	1968/69
	Thousand Acres					
Turkey				1	420	1780
Iran						25
Afghanistan				5	65	300
Nepal			105	16	61	133
West Pakistan		10	761	250	2365	6000
East Pakistan	1	166	382			20
India	2142	4409	6500	1278	7269	10000
Ceylon			17			
Burma		7	470			
Malaysia	104	157	225			
Laos	1	3	4			
Vietnam		1	109			
Indonesia			417			
Phillipines	204	1733	2500			
Total	2452	6486	11490	1550	10180	18258

Source: D. G. Dalrymple, Imports and Plantings of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations, Foreign Agricultural Service, U.S. Department of Agriculture, in cooperation with Agency for International Development, (Washington, D.C., Nov.1969), pp. 4-23.

(a) factor and product price relationships in tropical and sub-tropical Asia before the green revolution had already been favorable enough to make it rewarding to develop a new technology represented by the HYV's; (b) only when international and national agencies responded after a considerable time lag to these favorable price relationships and provided the key input, the crop breeding research of high caliber scientists, was this new technology actually developed and made available to farmers; and (c) this change in technology is biased towards facilitating the substitution of an increasingly abundant factor for an increasingly scarce factor in the economy. A critical element in this process is a response by public agencies to economic incentives rather than the response by profit maximizing firms on which traditional arguments of induced innovation have been based [2/].

In order to explore this process the experience of transmitting rice production technology from Japan to Taiwan and Korea during the inter-war period seems particularly instructive. Although it was based on a colonialistic motivation, it represented a significant success in the transmission of agricultural technology through the transfer of scientific knowledge embodied in scientists, with a deliberate intention to transform traditional peasant agriculture. The long-term historical statistics of product and factor prices in Japan, Taiwan and Korea enable us to infer the price mechanisms which induced the transmission of technology through scientific research; this appears to parallel what is happening in Asia today.

First we will discuss the nature of HYV's in their relation to a critical complementary input -- fertilizer. Then we will review the fertilizer-rice price ratios which prevailed in selected Asian countries on the eve of the green revolution, in contrast with the time-series data for Japan. From these observations we will postulate a hypothesis concerning the innovation inducement mechanism. This hypothesis will be tested against the experience of Japan, Taiwan and Korea. Our discussion will be concentrated on rice because the experience of Japan, Taiwan and Korea is concerned primarily with rice [3/].

I. An Induced Innovation Hypothesis for the Green Revolution

High yielding varieties including those involved in the green revolution are in general characterized by high fertilizer responsiveness. Their fertilizer-responsive capacity is realized only when they are accompanied by better husbandry practices (e.g., weed and insect control) and by adequate water control. Traditional varieties have long survived with little fertilization under unfavorable environmental conditions, including a precarious water supply and rampant weeds. Those varieties represent optimum technology under such conditions [4/]. Consequently, without fertilization they tend to have higher yields than improved varieties, but they are less responsive to heavier fertilizer application.

Table 2 compares the yield response of indigenous varieties in East Pakistan and of improved varieties in Japan at two levels of fertilization. It shows that the yields of the traditional varieties are approximately as high as the improved varieties at low levels of fertilization, but the response to the increase in nitrogen input is primarily one of increasing the output of straw. These relations may be drawn as u_o and u_1 in Figure 1, which represent the fertilizer response curves of traditional varieties and HYV's respectively. It implies that technical progress due to the development of HYV's represents a local shift of the production function rather than a global shift [5/]. For farmers facing u_o a decline in the fertilizer price relative to product price from p_o to p_1 would not be expected to create much increase in fertilizer application or in rice yield. The benefit of a decline in the fertilizer price can only be fully exploited if u_1 is made available to farmers through the selection of more responsive varieties.

Table 2. Yield response to nitrogen input by rice varieties.

Variety	Yield (lb/acre) at the levels of N (1) 95 lb./acre Paddy	Straw	(2) 150 lb./acre Paddy	Straw	Marginal Product of N $\frac{(2)-(1)}{55}$ Paddy	Straw
Habiganj[a]	4785	7948	4372	10478	-7.5	46.0
Batak[a]	5445	9488	5875	11743	7.8	41.0
Kamenoo[b]	5417	5500	6077	7617	12.0	38.5
Norin 1[c]	6352	7205	7700	8225	24.5	18.5
Norin 87[c]	5118	6352	6517	7892	25.4	28.0
Rikuu 232[c]	5802	6902	7425	8553	29.5	30.0

a Indigenous varieties in East Pakistan.

b A variety selected by a veteran farmer, which became prevalent in Japan for 1905-1925.

c Varieties selected through hybridization by agricultural experiment stations in Japan after the nation-wide coordinated experiment system called "Assigned Experiment System" was established in 1926-27.

Source: Institute of Asian Economic Affairs, <u>Ajia no Inasaku</u> (Rice Farming in Asia), (Tokyo, 1961), p. 14.

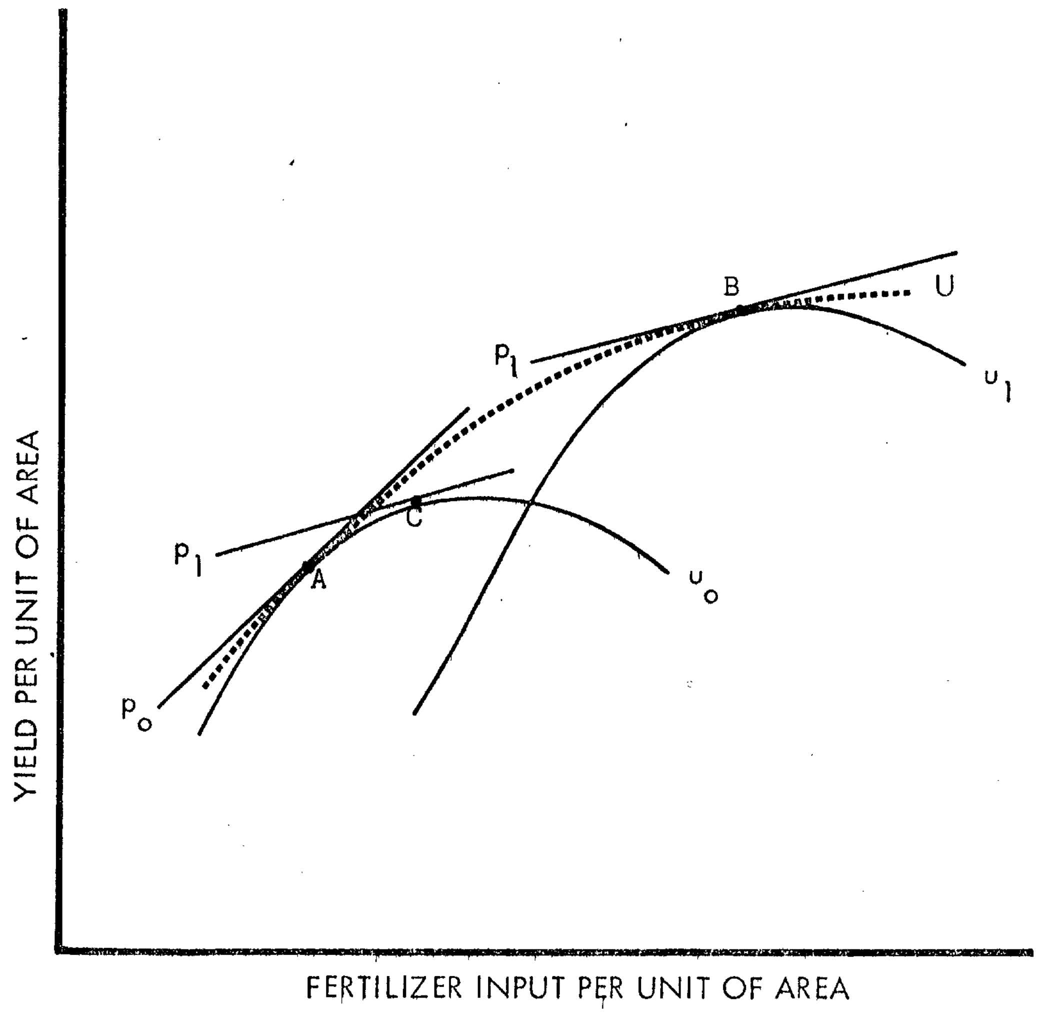

Figure 1. Hypothetical process of the induced development of a high yielding variety (HYV).

u_o represents a fertilizer response curve of traditional variety; u_1 a response curve of HYV; U a meta-production function -- an envelope of all potentially existing response curves; and p_o and p_1 higher and lower fertilizer-grain price ratio lines respectively.

Conceptually it is possible to draw a curve such as U on Figure 1, which is the envelope of many response curves, each representing a variety with a different degree of fertilizer responsiveness. We may call it the "meta-production function" representing the potential inherent in nature. In the short run, in which factor substitution is circumscribed by the rigidity of existing capital and equipment, production relationships are best described by an activity with relatively fixed factor-factor and factor-product ratios. In the long run, where the constraint exercised by existing capital disappears and is replaced by the fund of available technical knowledge, including all alternative feasible factor-factor and factor-product combinations, production relationships can be adequately described by the neoclassical production function. In the secular period of production, in which the constraints given by the available fund of technical knowledge is further relaxed to admit all potentially discoverable knowledge, production relationships can be described by the meta-production function which describes all potentially discoverable technical alternatives. In this context technical knowledge has the same properties as "putty clay" capital; the ex ante choice of technical alternatives is flexible along the meta-production function; but in ex post, once technical knowledge is embodied in a certain variety, the choice of alternative activities is constrained by a response curve of that particular variety.

It is hypothesized that the adaptation of agriculture to new opportunities in the form of lower relative prices of modern inputs involves an adjustment to a new optimum along this meta-production function.

Adjustments along the meta-production function involve time and costs. The development of fertilizer responsive HYV's requires investment in research.

Better husbandry practices must be developed and learned. Complementary investment in irrigation and drainage is required to secure adequate control of water. Above all, it takes time to reorient the efforts of public agencies to such directions in response to price changes.

These processes may be inferred with respect to Table 3 which compares, for Japan and other selected countries in Asia, the price of fertilizers relative to the price of rice and rice yield per hectare of paddy area planted. It shows (a) a rice yield per hectare in Japan that is higher than yields in Southeast Asian countries is associated with a considerably lower ratio of the price of fertilizer to the price of rice; (b) a remarkably high inverse association between rice yield per hectare and the fertilizer-rice price ratio in the time series data for Japan; (c) a substantial decline in the fertilizer-rice price ratios in the Asian countries from 1955-57 to 1963-65 is associated with little gains in rice yield per hectare; and (d) fertilizer-rice price ratios in the Southeast Asian countries today are much more favorable than those which prevailed in Japan at the beginning of this century or before.

If we consider the yield comparisons in Table 2, it seems reasonable to infer that the considerable differences in the rice yield and the price ratios between Japan and Southeast Asian countries can best be interpreted in terms of the different fertilizer response curves as shown by u_o and u_1 in Figure 1. The consistent rise in the rice yield per hectare accompanied by the consistent decline in the fertilizer-rice price ratio in the historical experience of Japan indicates a process of movement along the meta-production function. When we consider the history of the development of Japanese agricultural technology, the deliberate efforts of veteran farmers to select and propagate

Table 3. Fertilizer-rice price ratios and rice yields per hectare in selected Asian countries and in Japan 1883-1962.

Country	Currency unit	Price of Fertilizer: per m. ton of nitrogen (1)	Price of Rice: per m. ton of milled rice (2)	Fertilizer-rice price ratio (1)/(2)	Rice yield per hectare: m. ton of paddy (3)
Cross-country comparison					
1963-65					
India	rupee	1750	595	2.9	1.5
Pakistan (East)	rupee	1632	780	2.1	1.7
Philippines	peso	1048	530	2.0	1.3
Thailand	U.S. dollar	229	70	3.3	1.6
Japan	1000 yen	97	99	1.0	5.0
1955-57					
India	rupee	1675	417	4.0	1.3
Pakistan (East)	rupee	1322	511	2.6	1.4
Philippines	peso	962	352	2.7	1.1
Thailand	U.S. dollar	393	79	5.0	1.4
Japan	1000 yen	119	77	1.5	4.8
Japan's time series					
1958-62	1000 yen	100	85	1.2	4.9
1953-57	1000 yen	113	75	1.5	4.2
1933-37	yen	566	208	2.7	3.8
1923-27	yen	1021	277	3.7	3.6
1913-17	yen	803	125	6.4	3.5
1903-07	yen	815	106	7.7	3.1
1893-97	yen	670	69	9.7	2.6
1883-87	yen	450	42	10.7	---

Notes to Table 3.

(1) Price paid by farmers. Cross country data: average unit price of nitrogen contained in ammonium sulphate; 1963-65 data are the averages for 1962/63 - 1964/65; 1955-57 data are the data of 1956/57; government subsidies of 50 percent for 1963-65 and of 40 percent for 1955-57 are added to Pakistan's original data. Japan's data: average unit price of nitrogen contained in commercial fertilizers.

(2) Wholesale price at milled rice basis. Japan's data are converted from brown rice basis to milled rice basis assuming 10 percent for processing cost.

(3) Japan's data converted from brown rice basis to milled rice basis assuming 0.8 for a conversion factor.

Source:

Cross-country data: FAO, Production Yearbook, various issues.
Japan's data: Kazushi Ohkawa, et. al. (ed.), Long-term Economic Statistics of Japan, Vol. 9, (Tokyo, 1966), pp. 202-203; Nobufumi Kayo (ed.), Nihon Nogyo Kisotokei, (Tokyo, 1958), p. 514; Toyokeizaishimposha, Bukku Yoran, (Tokyo, 1967), p. 80; Institute of Developing Economies, One Hundred Years of Agricultural Statistics in Japan, (Tokyo, 1969), p. 136.

superior varieties, the vigorous activities in experiment stations and other research institutions, and the remarkable shifts of rice varieties over time, the hypothesis of moving along a fixed production response curve (u_0) will be violated.

We are left with some intriguing questions. Why did not the rice yields per hectare of the Southeast Asian countries increase much from 1955-57 to 1963-65 in spite of the substantial decline in the fertilizer-rice price ratio? And, why did rice yields in these countries remain at low levels despite fertilizer-rice price ratios which were more favorable than in Japan at the beginning of this century? One answer must be attributable to the time lag required to move along the meta-production function. This time lag tends to be extremely long in situations characterized by lack of adequate institutions and human capital to generate the flow of new techniques. It appears that before the 1960's the countries in Southeast Asia, even though the fertilizer-rice price ratio declined from p_0 to p_1, could not move from A to B in Figure 1 because of the lag in the response by public agencies to create a new technology (u_1). They seem to have been trapped at C: This point represents an equilibrium for a response curve (u_0) that is actually available for farmers but a disequilibrium in terms of potential alternatives described by the meta-production function (U).

The dramatic appearances of the HYV's since about 1965 can be interpreted in this light. The efforts of the International Rice Research Institute in the Philippines, of the Japanese plant breeders in Malaysia under the Colombo Plan, of the Indian Council of Agricultural Research and of various other national research organizations were designed to develop fertilizer-responsive HYV's.

By the mid-1960's a number of varieties satisfying these requirements including IR-8, Malinja, and ADT-27 were being released to farmers [6]. We hypothesize that these innovations were induced by a potential high pay-off of investment in crop breeding research, enabling the adjustment from C to B. Because the "proto-type" HYV's were already in existence in Japan, the United States and other temperate zone rice producing countries, this major adjustment can be brought about with relatively minor research investment. A critical element is that this high pay-off of investment in research is for society but not for individual firms. Asian peasants are in too small units to capture enough gains to pay for research costs. It is only when public agencies perceive this opportunity and allocate funds for this direction that the adjustment is made feasible.

Declines in the price of fertilizer relative to the price of rice during the 1950's and the 1960's were the results of (a) increased productivity in the chemical fertilizer industry in the developed countries which was transmitted to less developed countries through international trade, and (b) rapid shifts in rice demand due to population growths which outpaced production increases. In most parts of Asia characterized by high population density the increases in population and food demand represent a pressure against land. It seems reasonable to hypothesize that the pay-off of the crop breeding research was enhanced by the nature of the HYV's facilitating the substitution of an increasingly abundant factor (fertilizer) for an increasingly scarce factor (land) in the economy. Agricultural research which led to the green revolution would not have been attempted unless the prices of fertilizer were relatively low and declining rapidly, making it profitable for farmers to adopt the fertilizer-responsive HYV's. Even if attempted, the results would have been similar to the granting of high powered tractors to those countries, as was done in the earlier technical assistance program, since both attempts were incompatible with price relationships among factors and products. Success of research depends on whether it is directed in the generation of a technology compatible with the market prices that reflect product demand and factor endowments of the economy.

II. Transmission of Rice Production Technology From Japan to Taiwan and Korea: A Hypothesis Testing

In this section we attempt to test the hypothesis proposed in the previous section against the experience of transmitting Japanese rice technology to Taiwan and Korea during the 1920's and the 1930's. To be more specific, a hypothesis to be tested is that (a) fertilizer-rice price ratios in Taiwan and Korea before the 1920's had already been favorable enough to make it rewarding to develop the fertilizer-responsive HYV's; (b) only when colonial governments, pressed by the demand of mother country, responded to this opportunity in investing in rice breeding research, were the HYV's adaptable to the local ecologies of Taiwan and Korea actually developed; and (c) these HYV's represent a technical change biased towards the fertilizer-using and land-saving direction that was compatible with changes in the factor endowments of the economy. As is the case with the green revolution, this represents a process of transmitting a "proto-type" agricultural technology existing in developed countries (Japan) to less developed countries (Taiwan and Korea), through the transfer of scientists. It is hypothesized that public investment in research leading to this technology transmission was induced by a high social pay-off expected from adjustment from a secular disequilibrium (C in Figure 1) to a secular equilibrium (B in Figure 1), although the social pay-off in this case was primarily in terms of the benefit of Japan rather than of Taiwan and Korea [7/].

Background

The green revolution represents the success of the development strategy of applying science to peasant agriculture with the ultimate goal of promoting overall economic growth. This was the process of agricultural development in Japan, Taiwan and Korea until the collapse of the Japanese Empire during World War II. The primary purpose was to finance and support industrial development in metropolitan Japan by generating agricultural surpluses through increased productivity. Technological potential was first exploited in domestic agriculture in Japan, and when it was exhausted the colonial agricultural development policy was launched.

This process is reflected in the movements in rice yield per hectare in Japan, Taiwan and Korea (Figure 2). The major source of rice supply to meet the increase in demand from developing industrial sectors of Japan through the first two decades of the 20th century was primarily due to yield increases in domestic agriculture.

Agricultural productivity growth of Japan in the Meiji Period (1868-1911) was supported by the propagation of the better farmers' techniques [8/]. With the reforms of the Meiji Restoration which set Japan for modern economic growth, feudal restraints imposed on farmers were removed. The Land Tax Revision granting fee simple titles to farmers increased the incentive of farmers to innovate. Exchange of seeds and technical information was encouraged by the government and it was facilitated by modern postal services and railways. The farmers responded to their opportunities vigorously. In response to a rapid decline in the fertilizer price relative to the product price, farmers selected more fertilizer-responsive HYV's by careful panicle picking. For example, the Shinriki variety, which diffused over wide areas in the western half of Japan, in a manner unequalled by any other variety since propagated, was selected in 1877 by Jujiro Maruo, a farmer in the Hyogo Prefecture. Similarly

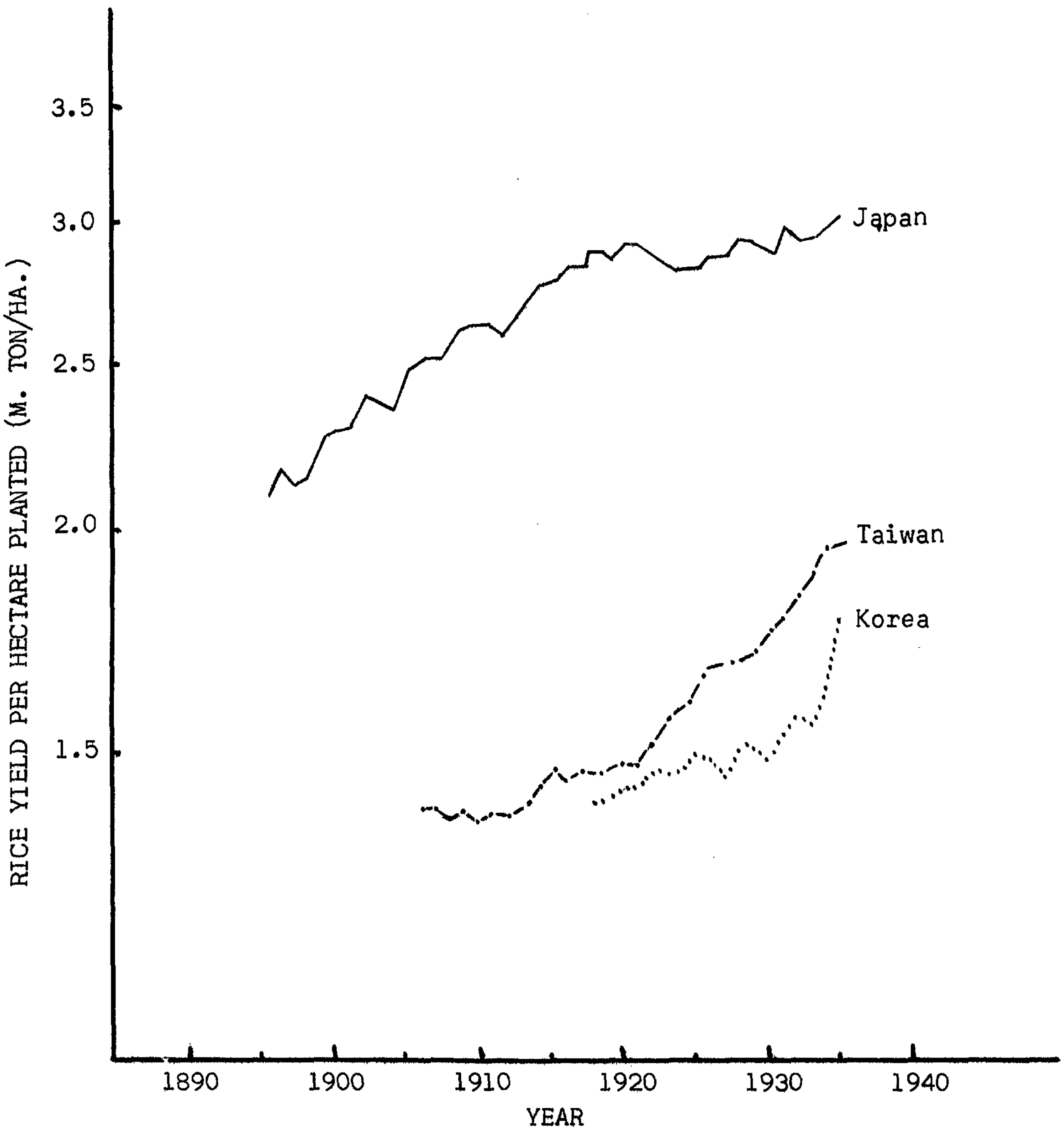

Figure 2. Rice yields per hectare planted for Japan, Taiwan and Korea, five-year moving average, 1895-1935.

Source: Japan Ministry of Agriculture and Forestry, Norimsho Ruinen Tokeihyo (Historical Statistics of the Ministry of Agriculture and Forestry), (Tokyo, 1945), p. 24; Taiwan Government-General, Taiwan Nogyo Nenpo (Yearbook of Taiwan Agriculture), (Taipei), various issues; Korea Government-General, Nogyo Tokeihyo (Agricultural Statistics), (Seoul), various issues.

the Aikoku variety (1889) in the Kanto District and the Kamenoo variety (1893) in the Tohoku District (both in the eastern part of Japan) were selected by farmers themselves. Those varieties were characterized by higher fertilizer responsiveness; they are less susceptible to lodging, insect and disease damage with higher nitrogen application.

The government tried to exploit the traditional technological potential by investing in scientific research and education. In its early days the major role of the experiment stations was to conduct simple tests comparing various varieties and practices. These simple experiments were effective using scientific principles to screen and tailor the farmers' techniques for nation-wide propagation.

It appears that this process of rice productivity growth in Meiji Japan -- a significant decline in the fertilizer-rice price ratio, the spread of improved varieties, increases in fertilizer input and rice yield per hectare from 1895 to 1915 (rows 1-4, Table 4) -- indicates movement along the meta-production function in response to a decline in the fertilizer-rice price ratio, as represented by a movement from A to B in Figure 1.

The development and diffusion of these high yielding varieties were also based on the relatively well established water control facilities in Japanese paddy fields. Even at the beginning of the Meiji Restoration almost 100 percent of the paddy fields in Japan were irrigated, although the water supply was not necessarily sufficient and appropriate drainage was lacking in many cases [9/]. These irrigation systems were built during the long peaceful feudal Tokugawa period, primarily by communal labor under the encouragement of feudal lords.

By adequately screening and tailoring veteran farmers' varieties and practices by rather simple experiments, Japan was able to exploit the sub-

Table 4. Fertilizer-rice price ratio, seed improvement, fertilizer input and rice yield per hectare: Japan, Taiwan and Korea, selected years.

	1895	1905	1915	1920	1925	1930	1935
Japan							
(1) Fertilizer-rice price ratio (m. tons of brown rice purchasable by a ton of $N + P_2O_5 + K_2O$)	7.0	5.2	4.4	3.5	3.0	3.0	2.2
(2) Ratio of area planted in improved varieties to total paddy area planted in rice	0.07	0.30	0.44	0.42	0.42	0.55	0.56
(3) Fertilizer input per ha. (kg. of $N + P_2O_5 + K_2O$)	13	24	49	63	79	96	104
(4) Rice yield per ha. (m. tons of brown rice)	2.07	2.46	2.79	2.91	2.84	2.89	3.04
Taiwan							
(5) Fertilizer-rice price ratio (m. tons of brown rice purchasable by a ton of $N + P_2O_5 + K_2O$)					4.5	4.5	4.2
(6) Ratio of area planted in Ponlai varieties to total paddy area planted in rice					0.13	0.23	0.46
(7) Fertilizer input per ha. (kg. of $N + P_2O_5 + K_2O$)				12[a]	20	33	55
(8) Rice yield per ha. (m. tons of brown rice)			1.47	1.47	1.63	1.75	1.97
Korea							
(9) Fertilizer-rice price ratio (m. tons of brown rice purchaseable by a ton of $N + P_2O_5 + K_2O$)				3.3	3.0	3.5	2.5
(10) Ratio of area planted in Japanese varieties to total paddy area planted in rice				0.22	0.57	0.72	0.84
(11) Fertilizer input per ha. (kg. of $N + P_2O_5 + K_2O$)				1.3	3.4	12	28
(12) Rice yield per ha. (m. tons of brown rice)				1.43	1.50	1.48	1.82

Notes to Table 4.

Data are five year averages, centering at the years shown except for arable land area which is measured at the years shown.

(1) Unit price of plant nutrients in commercial fertilizer divided by unit price of rice. Source: Kazushi Ohkawa, et. al. (ed.), Long-term Economic Statistics of Japan since 1868 (abbreviated as LTES), Vol. 9 (Tokyo: Toyokeijaishimposha, 1966), pp. 146-147, 166-168 and 194-201.

(2) Estimated by linear interpolation from the data in Yujiro Hayami and Saburo Yamada, "Technological progress in Agriculture," in L. R. Klein and Kazushi Ohkawa (ed.), Economic Growth: The Japanese Experience Since the Meiji Era, (Homewood: Irwin, 1968), pp. 135-161.

(3) Plant nutrients contained in commercial fertilizers per hectare of arable land. Source: LTES Vol. 9 pp. 196-201 and 216-217.

(4) Yield per hectare planted in paddy rice. Source: Japan Ministry of Agriculture and Forestry, Norinsho Ruinen Tokeihyo (Historical Statistics of the Ministry of Agriculture and Forestry), (Tokyo, 1945), p. 24.

(5) Unit price of plant nutrients in commercial fertilizer divided by unit price of rice. Commodity flow estimates of fertilizer consumption (production + import - export) after 1932 were spliced to the estimates for preceeding years based on rural survey by multiplying by the 1929-32 average ratio. Source: Michio Kanai, Taiwan, in Chujiro Ozaki (ed.), Koshinkoku Nogyo Hatten no Shojoken (Conditions of Agricultural Development in Less Developed Countries), (Tokyo: Institute of Developing Economies, 1968), pp. 82-112 and 101; Taiwan Government-General, Taiwan Nogyo Nenpo (Yearbook of Taiwan Agriculture), various issues.

(6) Taiwan Nogyo Nenpo, various issues.

(7) Plant nutrients contained in commercial fertilizers applied to crops other than sugar cane per hectare of arable land area minus sugar cane area. Kanai's estimates of total plant nutrient consumption were apportioned to sugar cane and other crops in proportion to the values of commercial fertilizers applied to sugar cane. The data of fertilizer applications by crops are available only until 1932. The data after 1932 were estimated by fixing the compositions to 1929-32 values. Source: Kanai, op. cit.; Taiwan Nogyo Nenpo, various issues. The 1920 figure is estimated by linear extrapolution using the rate of growth from 1925 to 1930.

(8) Yield per hectare planted in paddy rice. Source: Taiwan Nogyo Nenpo, various issues.

Notes to Table 4. (continued)

(9) Unit price of plant nutrients in commercial fertilizers divided by unit price of rice. Source; Korea Government-General, Nogyo Tokeihyo (Agricultural Statistics), various issues.

(10) Nogyo Tokeihyo, various issues.

(11) Plant nutrients contained in commercial fertilizers per hectare of arable land. Source: Nogyo Tokeihyo, various issues. Total quantities of plant nutrients were calculated from the quantities of individual fertilizers consumed using the following conversion factors:

	Fish meal	Bone meal	Other animal matters	Soybean cake	Other oil seed cakes	Brans	Other vege-table matters	Ammo-nium sulphate	Sodium nitrate	Super-phos-phate of lime	Potas-sium sulphate	Other chemical fert.	Mixed fert.
N	0.08	0.04	0.08	0.07	0.06	0.02	0.06	0.21	0.15	0	0	0.08	0.08
P_2O_5	0.07	0.23	0.07	0.01	0.03	0.04	0.02	0	0	0.17	0	0.08	0.08
K_2O	0.03	0	0.03	0.02	0.01	0.02	0.02	0	0	0	0.50	0.05	0.05

(12) Yield per hectare planted in paddy rice. Source: Nogyo Tokeihyo. various issues.

stantial indigenous technological potentials in agriculture. Domestic rice production was able to supply about 95 percent of domestic consumption during the period of the big spurt in industrialization between the Russo-Japanese War (1904-05) and World War I. The technological potential was being exhausted, however, as it was being exploited in the absence of a supply of new potential. As already mentioned, the experiment stations in their early days contributed to agricultural productivity growth by exploiting indigenous potential rather than by supplying new potential. The national experiment station gradually moved to conduct more basic research, including original crop breeding projects at the Kinai Branch by cross-breeding (1904) and at the Rikuu Branch by pure line selection (1905). Results of major practical significances lagged, however, for more than two decades. [10/]

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 culminating in the Kome Sodo (Rice Riot) in 1918, which swept over all the major cities in Japan.

Japan was then faced with a choice between high rice prices, high cost of living and high wages on the one hand and a drain on foreign exchange by large-scale rice imports on the other. Both were unfavorable to industrial development. The reaction of the government was to increase rice imports from Taiwan and Korea by developing rice production in these colonies while suppressing domestic consumption of rice in Taiwan and Korea through the squeeze on income by taxation and government monopoly sales. According to Seiichi Tobata, until the Rice Riot"-- development efforts in Taiwan were concentrated on sugar production and little was done in Korea. It was claimed that the development of rice production in those overseas territories should be suppressed since it was to foster the competitor against Japanese Agriculture --". 11/

Under the program titled Sanmai Zoshoku Keikaku (Rice Production Development Program), the 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 ecologies of Korea and Taiwan. The expenditure for agricultural development by the Government-General of Korea before and after the start of the Rice Production Development Program (1920) clearly indicates this drastic policy reorientation: The total agricultural development expenditure jumped from a 1915-19 total of 3.5 million yen to a 1920-24 total of 18.6 million yen; expenditure for experiment stations from 1.1 million yen to 2.8 million yen; the expenditure for land improvement projects including irrigation and drainage facilities from only 334 thousand yen to as much as 12 million yen. 12/ Rapid increases in rice yields in Taiwan and Korea, accompanied by stagnation in Japanese rice yields, was the result of this policy reorientation 13/.

Taiwan Case

The most spectacular success was attained in Taiwan with the development of the Ponlai varieties. The Ponlai varieties are rice varieties "developed by hybridization of Japanese varieties or between Japanese and traditional Taiwan (Chailai) varieties to have photo-sensitivities different from the original Japanese varieties." 14/ They are more fertilizer responsive, and high yielding with adequate water control and cultural practices and are better suited to Japanese tastes than are the Chailai varieties (Indica).

It was not easy to adapt Japanese varieties to the tropical climate of Taiwan. Even before the policy reorientation after the Rice Riot, when the effort of the Government-General was directed to improving the Chailai varieties to satisfy Taiwan's domestic demand, research to adapt Japanese varieties to tropical ecology had been conducted, although on a small scale. A breakthrough came in the finding by Eikichi Iso of the Agricultural Division, Central Research Institute of the Government-General, that the Japanese varieties could be grown successfully by reducing the sojourn of the rice seedling in the nursery bed to half of the period used in traditional practice [15/].

With this breakthrough and under the pressing demand of Japan, the Government-General shifted emphasis from improvement of the Chailai varieties to development and propagation of the Ponlai varieties. Areas planted with the Ponlai varieties grew from 400 hectares in 1922, the first year this statistic was recorded, to 131 thousand hectares in 1930, and 296 thousand hectares (almost one half of the paddy field area planted) in 1935. This rapid diffusion was based on the high pay-off of the Ponlai varieties. According to the rice production cost survey conducted by the Government-General in 1926-27, both profit (total revenue minus total cost) and farm family income (profit plus family labor wages) per <u>chia</u> (0.97 hectare) were very much higher with the Ponlai varieties than with the Chailai varieties (Table 5).

In the cost comparison in Table 5 differences in (a) fertilizer expense (b) wages and (c) rent are particularly significant. Larger expenditures for fertilizer for the production of Ponlai varieties clearly reflect their higher fertilizer responsiveness. Higher wage costs show that the Ponlai varieties require more labor and better husbandry, including checkrow planting, deep plowing, more intensive weeding and insect control. Higher rent for the Ponlai

Table 5. Comparison of the costs of Ponlai and Chailai rice production per chia.

	1926 Second Crop			1927 First Crop		
	Ponlai (1)	Chailai (2)	(1)-(2)	Ponlai (3)	Chailai (4)	(3)-(4)
	yen					
Seed	8.12	3.97	4.15	8.31	4.17	4.14
Fertilizer[a]	51.26	25.50	25.76	63.58	26.90	36.68
Wage	112.38	93.86	18.52	126.20	103.83	22.37
Family labor	73.30	54.57	18.73	81.51	62.75	18.76
Hired labor	39.08	39.29	-0.21	44.69	41.08	3.61
Implements and building	3.76	4.24	-0.48	4.55	4.83	-0.28
Miscellaneous	2.46	1.01	1.45	9.25	11.73	-2.48
Tax and rate	1.41	1.66	-0.25	1.81	1.57	0.24
Rent	147.20	121.70	25.50	176.40	133.42	42.98
Total cost	326.59	251.94	75.15	390.10	286.45	103.65
Total revenue[b]	382.04	285.31	96.73	466.76	285.26	181.50
Profit[c]	55.45	33.37	22.18	76.66	-1.19	77.85
Farm family income[d]	128.75	87.94	40.81	158.17	61.56	96.61

a. Include self-supplied fertilizers b. Include the value of straw
c. Profit = Total revenue - Total cost
d. Farm family income = Profit + wage for family labor
Sources of data:

Taiwan Government - General, Bureau of Colonial Development, Shuyonosanbutsu Keizai Chosa (Economic Survey of Major Agricultural Products) No. 6 (pp. 11, 48-49, 62-63, 82-83, 112-113, 241, 249) and No. 9 (pp. 11, 13, 15, 17, 50-51, 64-65, 118-119, 152-153), Taipei, 1928.

Data are for tenant farmers.

varieties indicates that these varieties were grown in areas with better water control. It appears that the economic implications of the Ponlai varieties for Taiwan in the 1920's were essentially equivalent to those of "miracle rice" in the green revolution today 16/.

A remarkable aspect of the rapid diffusion of the Ponlai varieties during the 1920's and 1930's is that it was not accompanied by an appreciable decline in fertilizer prices relative to rice prices, as was the case with the improved varieties in Japan prior to 1920 (Table 4). As discussed previously, the spread of improved varieties in Japan accompanied by a decline in the fertilizer-rice price ratio suggests movement from A to B in Figure 1. In contrast, the rapid propagation of the Ponlai varieties in Taiwan without any significant decline in fertilizer-rice price ratio seems to indicate movement from C to B. Since Taiwan had been included in a common market of the Japanese empire, it seems reasonable to assume that the fertilizer price in Taiwan declined relative to rice price in parallel with its decline in Japan prior to 1920 (from p_o to p_1). In the absence of comparable levels of development of scientific knowledge in Taiwan, this opportunity could not be exploited, and rice production in Taiwan was trapped at C on the response curve of the Chailai varieties (u_o). When science embodied in foreign (Japanese) agricultural scientists was applied to this situation in response to the demand of the mother country, the potential was exploited through the dramatic development and propagation of the Ponlai varieties (u_1).

Korean Case

The Korean experience as summarized in Table 4 indicates: (a) the ratio of the price of fertilizer relative to the price of rice was almost as low as in Japan, (b) propagation of Japanese varieties in the 1920's did not accompany a significant reduction in the relative price of fertilizer, and (c) in spite of an earlier start in propagation of Japanese varieties, fertilizer input per hectare in the 1920's was at a much lower level than in Taiwan and the rice yield did not start to increase until around 1930.

Korea was situated closer to Manchuria, which was Japan's major supplier of nitrogen in the form of soybean cake until the 1920's. In the 1930's Japanese industrialists were attracted by abundant hydro-electric power built large-scale modern nitrogen plants in North Korea. Korean agriculture thus had access to cheaper sources of plant nutrients than did Taiwan. Rapid diffusion of Japanese rice varieties and rapid yield increases, in spite of rather stagnant relative prices of fertilizer, can be explained in terms of the movement from C to B in Figure 1. This is the same as in the case of Taiwan.

An apparent contradiction appears: in spite of an earlier start in the diffusion of Japanese varieties, the level of fertilizer input per hectare was low and the yield take-off lagged in relation to that in Taiwan. The key to this contradiction seems to be the differences in the level of irrigation and water control. Table 6 compares progress in paddy field irrigation between Taiwan and Korea. Since data on the area of irrigated paddy fields are not available for Taiwan, we calculated the ratio of irrigated paddy field area on the assumption that irrigation was developed only for rice and sugar production (which seems a rather reasonable approximation). The ratios thus calculated check well with the ratios of double cropped paddy area. In Taiwan, irrigation is required for double cropping rice.

From Table 6 it is apparent that irrigation construction lagged in Korea

Table 6. Irrigation and double cropping ratios in paddy field: Korea and Taiwan, selected years.

			Year				
			1915	1920	1925	1930	1935
Taiwan							
(1)	Paddy area	1000 ha.	343	367	374	396	479
(2)	Sugar cane area	1000 ha.	83	105	127	106	118
(3)	Irrigated area	1000 ha.	239	268	350	442	466
(4)	Double cropping paddy area	1000 ha.		246	266	292	313
(5)	Ratio of irrigated area	(3) ÷ [(1)+(2)]	0.56	0.57	0.70	0.88	0.78
(6)	Ratio of double cropping area	(4) ÷ (1)		0.67	0.71	0.74	0.65
Korea							
(7)	Paddy area	1000 ha.	1168	1531	1551	1605	1668
(8)	Irrigated paddy area	1000 ha.			758	953	1152
(9)	Double cropping paddy area	1000 ha.	160	240	266	353	429
(10)	Ratio of irrigated area	(8) ÷ (7)			0.49	0.59	0.69
(11)	Ratio of double cropping area	(9) ÷ (7)	0.14	0.16	0.17	0.22	0.26

(1) Area of paddy field

(2) Area of sugar cane harvested

(3) Irrigated arable land area

(7) Area of paddy field

(8) Irrigated paddy field area

Sources:
Taiwan: Taiwan Government-General, Taiwan Nogyo Nenpo (Yearbook of Taiwan Agriculture), various issues.

Korea: Korea Government-General, Nogyo Tokeihyo (Nogyo Tokeihyo) and Chosen Tochikairyo Jigyo Yoran (Summary Report of Korean Land Improvement Projects), various issues.

compared with Taiwan. In terms of the ratio of irrigated paddy area to total paddy area, Korea in 1925 did not reach the level of Taiwan in 1915. Judging from the movements in double cropping ratios (which are not comparable with Taiwan in absolute level because of the different climate) it seems reasonable to assume that progress in water control in Korea was greatly accelerated during the 1925-1935 period. This is compatible with the expenditure patterns for land improvement projects of the Government-General as seen earlier. In the literature on Korean agriculture it is common to identify the lack of irrigation as the critical cause for low productivity. Tobata and Ohkawa wrote in 1935 [17/].

> "The first technical condition of rice production is nothing but water control. But paddy field in Korea is so called 'rain-fed paddy field', ... accordingly marshy paddy field with drainage difficulty, which is considered of low quality in Japan is considered good paddy field. ... Who would dare to apply fertilizers under such condition?"

It was natural to place a high investment priority on irrigation when the Rice Production Development Program was initiated in 1920.

The climate of Korea is much more similar to that of Japan than is Taiwan's. Rice varieties of northern Japan are directly transplantable to Korea. But due to the precarious water supply, even in most parts of the so-called "irrigated paddy field", Japanese varieties introduced in Korea were not the high fertilizer-responsive varieties. Koremochi Kato, Director of the Agricultural Experiment Station in Korea remarked in 1926 [18/]:

> "It is natural that our experiment station since its establishment has worked to select those from many Japanese varieties, which have

better results under low level of fertilization. ... But, as water control has been developing recently farmers have been increasing fertilizer application and have become dissatisfied with the results".

In response to the demand for fertilizer-responsive varieties the South Korea Branch of the Agricultural Experiment Station was set up in 1930 with the primary purpose of developing fertilizer-responsive HYV's. During the 1930's, varieties with higher fertilizer responsiveness such as Ginbozu and Rikuu No. 132 rapidly replaced less fertilizer-responsive Japanese varieties such as Tamanishiki and Kokurato. 19/

In short, the development of HYV's in Korea comparable to the Ponlai varieties lagged relative to Taiwan for almost a decade due to the constraint of water control, which worked to depress the pay-off of investment in developing the HYV's. We may then ask, why was irrigation developed earlier in Taiwan? Many factors were involved: (a) annexation of Korea to Japan occurred a decade later than for Taiwan, so that investment in infrastructure in general was later in starting 20/; (b) irrigation had been developed in Taiwan during the early days of colonization to promote the production of sugar cane, and the facilities could be utilized for rice production; (c) production of Korean rice (Japonica) had been a direct menace to Japanese rice producers and was suppressed, while Taiwan Chailai rice (Indica) was not a direct competitor; (d) the Taiwan Government-General enjoyed revenue surpluses during the half decade preceeding 1910 (called the "Golden Age" of the Taiwan Government-General's treasury) and could afford to invest in large-scale construction of physical infrastructure including railways, ports and irrigation. 21/

Transfer of Production Function: A Process of Biased Technical Change

We now understand that emergence and propagation of HYV's in Taiwan and Korea during the 1920's and 1930's can be represented by the movement from C to B in Figure 1. This movement was made possible by the organized research of Japanese agricultural scientists and investment in irrigation by the colonial governments. This process of technology transmission involved the transfer of "proto-type" Japanese rice production technology to Taiwan and Korea through coordinated adaptive research.

This process is illustrated in Table 7 which compares factor shares in the cost of rice production in Japan with those of the Ponlai and Chailai varieties in Taiwan. The factor shares in the case of the Ponlai varieties are very similar to those in Japan. If we assume a production function of the Cobb-Douglas type and equilibrium under competitive factor markets, the factor shares represent production elasticities of the respective inputs. In the propagation of the Ponlai varieties, Japan's rice production technology was assimilated by Taiwan.

Both in the cases of Japan and of the Ponlai varieties in Taiwan, fertilizer's share is larger and land's share (rent) is smaller than in the case of the Chailai varieties. This clearly reflects the fertilizer-using and land-saving character of new technology embodied in fertilizer-responsive HYV's. This bias in technical change was consistent with a land-saving demand of the Taiwan economy in which the population pressure against land was raising the price of land relative to the prices of other factors [22/].

Figure 3 shows the changes in fertilizer's share in the total output in Japan, Taiwan and Korea. Due to data limitations, self-supplied fertilizers such as manure and compost are not included in the fertilizer. In Taiwan,

Table 7. Factor shares in the cost of rice production, Japan and Taiwan.

Factor	Japan	Taiwan			
		Ponlai		Chailai	
	1925-27 average	1926 Second crop	1927 First crop	1926 Second crop	1927 First crop
Fertilizer[a]	15.9	15.7	16.3	10.0	9.4
Wage	35.8[b]	34.4	32.2	37.3	36.2
Rent	41.5	45.1	45.2	48.3	46.6
Others	6.8	4.8	6.3	4.3	7.2
Total cost	100.0	100.0	100.0	100.0	100.0

a Include self-supplied fertilizer

b Includes livestock labor

Japan: Calculated from Yukio Ishibashi, Teikoku Nokai Kome Seisanhi Chosa Shynsei (Compilation of Rice Production Cost Survey by the Imperial Agricultural Society), (Tokyo: The National Research Institute of Agriculture, 1961), pp. 82-95. Data are for tenant farmers.

Taiwan: Calculated from Table 4.

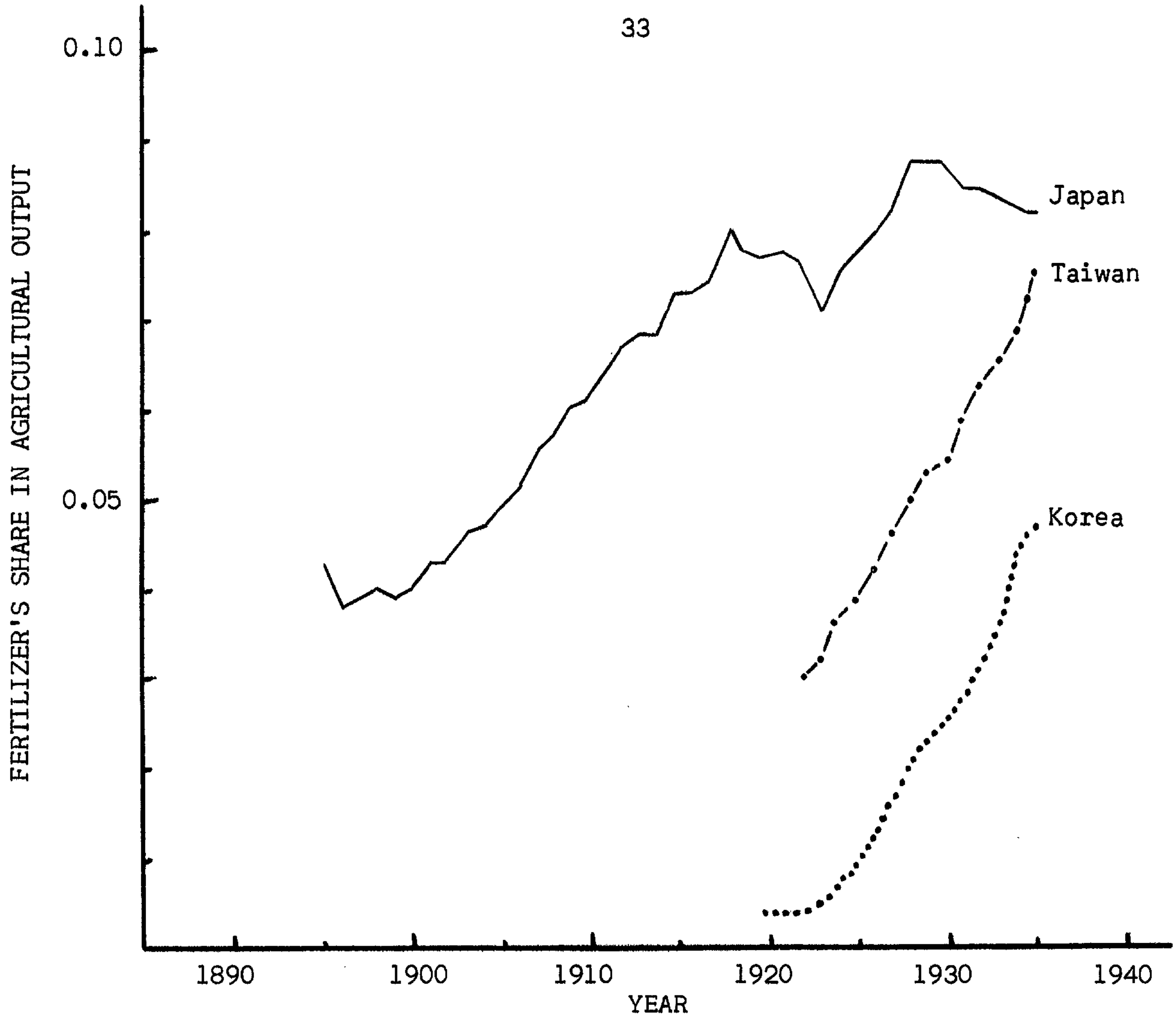

Figure 3. Fertilizer's share in agricultural output for Japan, Taiwan and Korea, five-year moving averages, 1895-1935.

Fertilizer's share is total value of commercial fertilizer consumption divided by gross value of agricultural production (both in current prices). In the case of Taiwan, fertilizers applied to sugar cane and sugar cane production are deducted, respectively, from fertilizer consumption and agricultural production (see estimation procedures in the note to Table 4).

Source: Kazushi Ohkawa, et al. (ed.), Long-term Economic Statistics since 1968, Vol. 9 (Tokyo, Toyokeizaishimposha, 1966), pp. 146-147 and 194-195; Taiwan Government-General, Taiwan Nogyo Nenpo (Yearbook of Taiwan Agriculture), various issues; Korea Government-General Nogyo Tokeihyo (Agricultural Statistics), various issues.

because of its special nature, the sugar cane sector is excluded from the calculations (fertilizer input in sugar cane is deducted from total fertilizer inputs and sugar cane output is deducted from total agricultural output). 23/ Remarkable associations exist between the movements of fertilizer's share and of rice yields per hectare (Figure 2) in Japan, Taiwan and Korea. This correspondence suggests strongly that growth in rice yields in these three regions was a process of replacement of traditional varieties by fertilizer-responsive HYV's (e.g., Chailai by Ponlai). It indicates the process of assimilation of Japanese technology by Taiwan and Korea. In other words, it represents the transfer of Japan's agricultural production function to Taiwan and Korea.

Fertilizer's share in Japan rose rapidly until the end of the 1910's, decelerating thereafter. This corresponds to the emergence and propagation of HYV's based on the exploitation of technological potential through a dialectic process of farmers' trials and scientific research, followed by the exhaustion of the potential, as discussed previously. This movement in fertilizer's share may appear to be similar to what Bent Hansen has called the learning process in reference to Egyptian and U.S. agriculture: the process by which farmers learn how to use new inputs, i.e., chemical fertilizers. 24/ Our interpretation of the experience of Japan, Taiwan and Korea is somewhat different. Even though farmers are well informed about the properties of new fertilizers, the shift to a new production function is difficult for individual farmers unless more fertilizer responsive HYV's are made available. The growth in fertilizer's share in Japan, Taiwan and Korea in Figure 3 involved not only farmers' learning but also the creation of new technology through a dialectic interaction between farmers' experience and scientific research.

III. Implications

We have hypothesized that the green revolution represents a movement from a production function which had been optimum for the factor and product prices which once prevailed in pre-modern society to another production function optimum for presently prevailing prices. This adjustment process lagged until the mid-1960's in most parts of Asia because of the lack of human capital and appropriate institutions to make this adjustment possible. Disequilibria in terms of meta-production function had accumulated. When coordinated research by the international teams of scientists was applied to this wide technological gap, the adjustment took a revolutionary form.

Japan's experience in the Meiji period indicates that the effective interaction among innovative veteran farmers and emerging agricultural science brought about continuous adjustments in response to declining fertilizer-rice price ratios in the creation and diffusion of more fertilizer responsive HYV's. This Japanese experience suggests that movements along the meta-production function can be accomplished relatively smoothly with the existence of indigenous human capital and an adequate infrastructure.

In the absence of this human capital, disequilibrium had mounted in Taiwan until about 1920 when Japan, to rescue her own food problem, transferred the technical knowledge embodied in agricultural scientists. This resulted in a dramatic success in the creation of the Ponlai varieties. The experience of Taiwan has special relevance in that it involved the transmission of technology to a different climatic condition, where the direct transfer of seeds and techniques was not feasible. Korea's adjustment lagged behind that of

Taiwan mainly because of a lag in the construction of physical infrastructure, especially irrigation. This Korean experience is particularly relevant for many areas in Southeast Asia where the adjustment to a new optimum through the diffusion of HYV's may be severely constrained both by limitations in human capital and by inadequate physical infrastructure, especially water control facilities. It appears possible to interpret the experience of Taiwan and Korea as representing the response of public agencies (colonial governments) to a potential high pay-off (for Japan) of investment in research leading to adjustments from secular disequilibria to equilibria for fertilizer-rice price ratios then prevailing.

Viewed from the historical perspective of agricultural development in Japan, Taiwan and Korea, the green revolution represents a response of national and international agencies to changes in product and factor prices, particularly rice and fertilizer prices, resulting from changes in rice demand and in the technology of fertilizer production during the 1950's and early 1960's. Also, it appears that technical change leading to the green revolution is biased towards saving the increasingly scarce factor (land) and using the increasingly abundant factor (fertilizer) in the economy. It clearly indicates a rational response of the public agencies to the economic forces. Although initial success has been achieved, the adjustment has not yet been completed. It can be sustained for some time if investment in research and irrigation is sufficiently high. It can be anticipated that sustaining progress will become increasingly difficult and costly as the adjustment process approaches its end. The supply of land with better water control and farmers with better knowledge and skill will progressively be exhausted. Larger areas of HYV's will require more research for protection from insects and pests and for protection of their high yielding properties from genetic degeneration. Above all, when technology in less developed countries approaches the proto-type technology of developed countries, further advancement by creating new breakthroughs will become more costly.

Countries experiencing the green revolution must prepare for the more difficult days to come. From the gains arising out of the green revolution they will have to finance investments in human capital formation and in institutional and physical infrastructures in order to sustain the green revolution. They will also need to finance industrial development if they are to lead the green revolution to overall economic development. If they fail, the green revolution will become abortive and increased yields will be eaten up by the rapidly increasing population. [25] Their success will, to a large extent, depend on the flexibility and efficiency of public institutions in responding to the economic opportunities.

NOTES

1/ For a concise documentation see U.S. Dept. of Agriculture, Economics Research Service, The Impact of New Grain Varieties in Asia, ERS - Foreign 275, (Washington, D.C., 1969). For dramatic aspects of these development see E. C. Stakman, Richard Bradfield and P. C. Mangelsdolf, Campaigns Against Hunger, (Cambridge: Harvard University Press), 1967. For a cautionary note see C. R. Wharton, Jr., "The Green Revolution: Cornucopia or Pandora's Box?," Foreign Affairs, (April 1969), pp. 464-476.

2/ For a representative historical study, see H. J. Habakkuk, American and British Technology in the Nineteenth Century, (Cambridge: Cambridge University Press, 1967). For theoretical development, see William Fellner, "Two Propositions in the Theory of Induced Innovations," Economic Journal Vol. 71 (June 1961), pp. 305-308; Charles Kennedy, "Induced Innovation and the Theory of Distribution," Economic Journal Vol. 74 (Sept. 1964), pp. 541-547; P. A. Samuelson, "A Theory of Induced Innovation Along Kennedy-Weisacker Line," The Review of Economics and Statistics Vol. 67 (Nov. 1965), pp 343-356.

3/ Data used for Japan, Taiwan and Korea cover periods after the cadastral surveys were completed (the cadastral survey was completed in 1890 in Japan; 1906 in Taiwan; 1918 in Korea). Reliability of data after the cadastral surveys are also subject to criticism by Nakamura. See J. I. Nakamura, Agriculture and Economics Development of Japan: 1873-1922 (Princeton: Princeton University Press, 1966); Incentives, Productivity Gap, and Agricultural Development in Japan, Taiwan and Korea (New York: Columbia University, mimeo, 1969). The questions regarding the official statistics of Japan raised by Nakamura have been widely discussed by Japanese and other scholars: Yujiro Hayami, "On the Growth of Japanese Agriculture: A Review Article," Rural Economic Problems, Vol. 4, No. 2 (May 1968), pp. 79-88; Yujiro Hayami and Saburo Yamada, "Agricultural Productivity at the Beginning of Industrialization," in Kazushi Ohkawa, B. F. Johnston and Hiromitsu Kaneda (eds.), Agriculture and Economic Development: Japan's Experience, (Tokyo: University of Tokyo Press, 1969), pp. 105-135; J. I. Nakamura, "The Nakamura Versus the LTES Estimates of Growth Rate of Agricultural Production," Keisai Kenkyu, Vol. 19 (October 1968), pp. 358-362. Appraisals by other scholars include: Henry Rosovsky, "Rumbles In the Ricefields: Professor Nakamura vs. the Official Statistics," Journal of Asian Studies, Vol. 27 (Feb. 1968), pp. 347-360, and Colin Clark's review of the Nakamura's book in the September 1967 issue of Journal of Agricultural Economics. Although the data for Taiwan and Korea need to be examined in more detail, we will resort in this study to official statistics.

4/ Tadayo Watanabe and Keizaburo Kawaguchi, "Increasing the Rice Yield in South and Southeast Asia," Asian Survey, Vol. 8, No. 10 (Oct. 1968), pp. 820-828.

5/ Implications of the "localized" technical progress are discussed in A. B. Atkinson and J. E. Stiglitz, "New View of Technological Change," Economic Journal, Vol. 79, No. 315, (Sept. 1969), pp. 573-578.

6/ For documentation on this process see U.S. Dept. of Agriculture, op. cit., 1969.

7/ This technology transmission involved relatively minor costs because it did not cause major changes in agrarian structure; peasant or small scale farms based on family labor continued to be basic units of production. Whether this will be the case with the green revolution remains to be a major unsolved question. See B. F. Johnston and John Cownie, "The Seed-Fertilizer Revolution and Labor Absorption," American Economic Review, Vol. 59, (Sept. 1969), pp. 569-582.

8/ Detailed analysis of this process is in Yujiro Hayami and Saburo Yamada, "Technological Progress in Agriculture," in L. R. Klein and Kazuski Ohkawa (eds.), Economic Growth: The Japanese Experience since The Meiji Period (Homewood, Ill.: Irwin, 1968), pp. 135-161. Discussions which follow are heavily based on Nogyo Hattatsushi Chosakai (Research Committee for the History of Agricultural Development), Nihon Nogyo Hattatsushi (History of Japanese Agricultural Development), ten volumes, (Tokyo: Chuokoronsha, 1953-1958), henceforth abbreviated as NNHS. Its abbreviated edition is Seizo Sasuda (ed.), Meiji Iko ni okeru Nogyo Gijutsu no Hattatsu (Progress of Agricultural Technology since Meiji), (Tokyo: Nogyo Gijutsu Kyokai, 1952) English readers may refer to Takekazu Ogura (ed.), Agricultural Development in Modern Japan, (Tokyo: Fuji Publishing Co., 1963).

9/ The fact that no statistics have ever been collected on the irrigated area shows that in Japan "paddy field" has been identified as "irrigated field". Construction of drainage facilities has been the primary objective in land improvement projects in Japan.

10/ The first major breakthrough in scientific rice breeding research was by Hiroshi Terao with the development of Rikku 132 in the Rikuu Branch. But the appreciable contributions of organized research in seed improvement to the national average yields occurred only after the establishment of a nation-wide organized research system, Norinsho Shitei Hinshu Kairyoshiken Seido (System of Seed Improvement Experiments of Varieties Assigned by the Ministry of Agriculture and Forestry) in 1926, and the creation and diffusion of Norin numbered varieties in the latter half of the 1930's as the research result of this system. Norin No. 1 was selected in 1931, but its large scale propagation occurred after 1935. See NNHS, Vol. 9.

11/ NNHS Vol. 9, p. 597.

12/ Kuro Kobayakawa, (ed.), Chosen Nogyo Hattatsushi: Seisakuhen (History of Korean Agriculture: Policy Volume), (Tokyo: Yuhokyokai, 1959), pp. 117-118.

13/ Increased supply of rice from the colonies depressed rice price and promoted agricultural stagnation in Japan. See the analysis of this process in Yujiro Hayami and V. W. Ruttan, "Korean Rice, Taiwan Rice and Japanese Agricultural Stagnation: An Economic Consequence of Colonialism," (St. Paul: University of Minnesota, mimeo, 1969), to be published in Quarterly Journal of Economics.

14/ Eikichi Iso, Horaimai Danwa (Discourse on the Ponlai Rice), (Yamaguchi: Udokukai, 1964), p. 18. Dr. Iso was Director of the Agricultural Division, The Central Research Institute of the Government-General of Taiwan. He is known for his contribution to development of the Ponlai Varieties.

15/ From 50-60 days to 30-40 days in the first crop; from 30-40 days to 15-20 days in the second crop. Iso, op cit. 1964, pp. 76-77.

16/ Randolph Barker and E. V. Quintana, "Returns and Costs for Local and High Yielding Rice Varieties," Philippine Economic Journal, Vol. 7, (Second Semester, 1969).

17/ Seiichi Tobata and Kazushi Ohkawa, Chosen Beikoku Keizairon (A Treatise of Rice Economy in Korea), (Tokyo: Nihongakujutsu Shinkokai, 1935), pp. 2-3.

18/ NNHS Vol. 9, pp. 176-177.

19/ Area planted in Tamanishiki and Kokurato was more than 30 percent of the area planted in rice and close to 50 percent of the area planted in Japanese varieties in Korea during the late 1920's. According to the experiments conducted by the Agricultural Experiment Station of the Government-General of Korea for 1927-29, those two varieties both recorded lower yields in high fertilization plots while such varieties as Ginbozu recorded higher yields in the high fertilization plots. NNHS Vol. 9, pp. 177-178.

20/ Taiwan was conceded to Japan by China in 1895 as a result of the Sino-Japanese War. Korea became a protectorate of Japan in 1905, and it became a territory of Japan in 1910.

21/ Shigeto Kawano, Taiwan Beikoku Keizairon (A Treatise of Rice Economy in Taiwan) (Tokyo: Yuhikaku, 1941), p. 11; Tadao Yanaihara, Teikokushuzika no Taiwan (Taiwan under Imperialism), (Tokyo: Iwanami, 1929), pp. 91-117.

22/ During the period 1920-35 arable land area increased by 11 percent and agricultural population by 21 percent, resulting in a decline in the land-man ratio by 10 percent in Taiwan. In Korea, during the same period, arable land area increased by 3 percent and agricultural population by 11 percent, resulting in a decline in the land-man ratio by 8 percent. Although comparable data are unavailable for Taiwan and Korea, Japan recorded a persistent rise in the price of arable land relative to the prices of other inputs from 1880 to 1960. See Yujiro Hayami and V. W. Ruttan, "Factor Prices and Technical Change: The United States and Japan, 1880-1960," (Staff Paper P69), Department of Agricultural Economics, University of Minnesota, July 1969.

23/ Sugar cane was produced either by plantations owned by sugar companies or by peasant farmers under the supervision and guidance of the sugar companies by contract. Fertilizer inputs in sugar cane were high even before the 1910's.

24/ Bent Hansen, "The Distributive Shares in Egyptian Agriculture, 1897-1961," International Economic Review Vol. 9, No. 2 (June 1968), pp. 175-194.

25/ The historical experience of Indonesia suggests this possibility. See Clifford Geertz, Agricultural Involution: The Process of Ecological Change in Indonesia, (Berkeley: University of California Press, 1966).