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TECHNICAL CHANGE AND AGRICULTURAL TRADE: THREE EXAMPLES (SUGARCANE, BANANAS, AND RICE)

By

R. E. Evenson, J. P. Houck, Jr. and
V. W. Ruttan

University of Minnesota

Department of Agricultural Economics

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

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Introduction

The invention, diffusion, and adoption of new technology has long been a crucial, yet imperfectly understood, feature of agricultural development. Throughout man's history, agricultural productivity increases have come about (1) by the diffusion of traditional crops, animals, tools, and methods into new areas of settlement and (2) by the introduction of new crops, animals, tools, and methods into traditional agricultural systems. /38/ During the last century, these processes have been accelerated by systematic efforts to identify, collect and diffuse superior crop varieties, livestock breeds and production practices throughout the major agricultural regions of the world. These systematic efforts have been supplemented by programs of adaptive research and extension designed to stimulate even more rapid diffusion of the best technologies from leading regions and farms to less-advanced regions and farms. /6/

Technological advance is particularly important to producers and consumers of farm products moving in international commerce. Foreign exchange earnings from exports of primary agricultural products underpin the development programs of many poorer nations. Farm income and employment in many developing nations are major components of overall national economic activity and depend heavily on foreign sales. On the other hand, consumers in both producing and importing nations have an important stake in international technological advance. When gains from innovation are passed along, consumers may benefit by lower prices and wider available selections of food and fiber products.

The purpose of this paper is to examine three cases which provide some insight into the character of international transmission of technical change and its economic impacts and implications. These cases focus on three separate commodities, sugarcane, bananas, and rice. Each case presents different facets of the international movement of technological innovation.

The section on sugarcane emphasizes the role of experiment station research in the development of new, higher yielding varieties and the subsequent diffusion of these varieties throughout the sugar-growing world. An attempt is made to assess the economic impact of the development of a new successful variety on the innovating nation and upon later adopters. The section on the banana trade illustrates how the development and adoption of disease-resistant banana varieties in Central America led to further innovations in marketing and processing techniques. The joint impact of these innovations is discussed in terms of changes in output, prices, and patterns of comparative advantage among producing nations. The section on rice trade illustrates how technical change in rice production in Japan was transferred to other producing nations, mainly Korea and Taiwan. The resulting increase in rice exports from these countries to Japan had substantial impacts on Japanese rice production and prices in the pre-World War II period. An attempt is made to measure these effects and to assess their economic implications.

Common threads run through each of these cases. A basic component of the technical changes examined in each of the three commodities is the development and diffusion of improved plant materials flowing from both public and private research efforts. In addition, each of these cases illustrates that, in one way or another, the pace of technical advance is linked to changes in economic incentives as viewed by individual producers and policy-making institutions. For each of these commodities, the complex web of international economic relationships has diffused the impact of a given technological advance far beyond the producers and nations actually developing the innovation or putting it into practice.

I. Sugarcane[1/]

This section explores the technical changes in sugarcane production that have resulted from the development and introduction of new sugarcane varieties. Four stages of progress in varietal development are identified and the relative contributions to varietal progress by the major sugarcane experiment stations of the world are evaluated. Inter-country and intra-country transmission of varieties is assessed and related to the stages of progress in varietal development. The implications for world sugar trade of the particular pattern of generation and transmission of technical change exhibited in this industry are explored.

Production and yield data are presented for eighteen major sugarcane producing countries in Table I.1. The relative position of a number of countries has changed considerably over time. The increased importance of Brazil and Mexico and the decline in production in Indonesia (Java) are especially striking. The yield data are incomplete, but the substantial increases taking place in India, South Africa, continental United States (Louisiana and Florida), Hawaii, Taiwan, Argentina and Australia (Queensland) are noteworthy.

The development of new varieties

A study of the history of attempts to improve yields through the development of new varieties reveals four important stages.

Stage I -- Selection of Natural (Wild) Varieties

Prior to 1887 the varieties planted were basically wild canes which had been selected over many years by planters in sugarcane-producing areas. These wild canes had originated in India, New Guinea and Java. In most cases, planters had relied on a single variety for many years. Planters experimented with new varieties but generally speaking the only varieties that survived over time were those resistant to the diseases prevailing in the area of production. Techniques of cultivation, irrigation, and processing were well developed in most producing countries by 1887, and sugar was an important world trade commodity by that time.[2]

Stage II -- Crossing of Varieties

In 1887 in the newly-founded experiment station in Barbados, British West Indies and in 1889 in the experiment station in Java, sugarcane seedlings were first produced through a process of sexual reproduction. [5, 40, 34] This was of great importance since it opened the possibility that varieties could be crossed. The cane plant ordinarily does not flower and produce seedlings readily. The inducement of flowering in the cane plant depends on temperature and light control and few experiment stations were successful in their attempts to produce seedlings in the early days of cane cross-breeding.[3]

Several experiment stations had notable successes in the development of the first new varieties. The Java station (Proefstatien Oost Java, P.O.J.) was the first to develop a new variety (P.O.J. 100) of commercial importance. It later added many more important varieties. Hawaii and Barbados had also developed important commercial cane varieties by 1900. The Coimbatore experiment station in India released the first of its Co. varieties in 1912. This station and the Java station were destined to develop varieties that would be planted commercially in every major cane-producing area of the world by 1930.

Stage III -- Breeding for Disease Resistance

Sugarcane disease did not diminish in importance with the introduction of the first new varieties. In many countries, the new varieties which yielded substantially more than the traditional native varieties were invaded by diseases within a few years.[5/] The Java station took the lead in developing disease-resistant varieties. In 1921 the variety P.O.J. 2878 was produced. Its pedigree included the first important Java variety, P.O.J. 100, as a grandparent. P.O.J. 2878 proved to be resistant to most important cane diseases and to be a high yielding variety as well. More than 50,000 acres were planted to this variety by 1926 -- a remarkable expansion in plant material from a single seedling in 1921. By 1929 more than 400,000 acres were planted in Java, and it was being planted in many other countries. This "wonder cane" became the most widely planted single variety in the world.

In the 1920-40 period the Coimbatore station in India also produced a number of important varieties which incorporated disease resistance and high-yielding ability. These varieties were planted widely throughout the world. Varieties developed in the British West Indies (Barbados) and Hawaii were also planted extensively outside the regions in which they were developed.

<u>Stage IV -- Breeding for Specific Soil and Climate Conditions</u>

The latest phase in the development of new varietal technology involves the breeding of varieties suited to the specific soil, climate, disease conditions and cultivating techniques of small regions. For the most part this breeding must be undertaken by the experiment station or stations in a specific region. The scope for international transmission of technical change through varietal transfer is limited. However, information about breeding techniques and the potential of certain varieties as parent stock have been exchanged, as have genetic materials.

More than 100 sugarcane experiment stations now exist in the world. Almost every important cane-producing country is now using locally-developed Stage IV varieties. This is illustrated by the data in Table I.2. The development of Stage IV varieties in Queensland, South Africa, Puerto Rico, and Louisiana is reflected in the percentage of acreage planted to locally-developed varieties in these countries.

Table I.3 shows the relative importance of the major varieties of sugarcane in the world during the 1940-64 period. The production figures are estimates of the overall importance of each variety in the major countries of the world during the 25 year period. Argentina is the only major producing country not included in this calculation.

Almost all of the major varieties during this period were bred prior to 1940. Most of them are examples of the third stage in breeding progress. The widespread planting of the Java (P.O.J) and Indian (Co.) varieties is evident. Barbados, the British West Indies station, and Hawaii also have produced varieties which have been used extensively in other countries. Only one native variety, Badila, had any commercial importance during this period. A number of important parent varieties and grandparent varieties were not important commercial varieties during the 1940-64 period. The P.O.J. 2364 variety was never a significant commercial variety, but it has been important as a parent to P.O.J. 2878 and several other varieties.

Table I.4 indicates the importance of Coimbatore and Java stations in the generation of new varieties. The Java station has been especially productive of parent and grandparent varieties. Almost all of the parent and grandparent varieties were produced in Java, Barbados, India, Hawaii and British Guiana -- the successful Stage II and III stations. A number of additional stations such as Cuba, Canal Point, (Florida) Queensland, South Africa, Taiwan, Mauritius,[6/] Brazil, British Honduras, Puerto Rico, and Peru are now important in producing varieties as a result of Stage IV activity.

If the period under concern had been 1955-65 instead of 1940-64, the latter group of stations would have had more importance because, by this time, most of the varieties produced in most countries were locally developed. Table 1.2 illustrates this point. Queensland, South Africa, Puerto Rico, and Louisiana are stations which did not figure importantly in the Stage II and III breeding work. They did test and select Stage II and III varieties from other countries. In recent years they have produced new varieties that have become increasingly important to their own sugarcane economies but, with one exception, have not been widely distributed to other countries. The exception is the variety N:Co. 310, bred in South Africa and later planted extensively in Taiwan.

The shift from early Taiwan varieties to N:Co. 310 in 1960 is evident from Table I.2. It is also evident that Taiwan again was producing important local varieties by 1965. Hawaii, like India and Java has been planting almost its entire acreage to its own varieties for a number of years. Mauritius produced some Stage II varieties, then dropped out in Stage III, but has participated in Stage IV.

<u>International Transmission of Varietal Changes</u>

Reference to Table I.3 indicates that the varieties of the major Stage II and III stations were in commercial production in many countries other than their country of origin. What is not obvious, however, is that the experiment station itself was an important factor in the international transmission of the P.O.J., Co., Hawaiian, and British West Indian varieties.

The South African case is instructive in this regard. The sugar industry had its beginnings in South Africa in 1849. Prior to 1880 several wild varieties imported from Java, Mauritius, and Indian were cultivated. A wild variety, Uba, was introduced in 1883 and proved to be more disease-resistant than the other varieties. For a period of fifty years it was the only important variety grown.

Some experimentation was carried on by planters to find new varieties during this fifty-year period. A number of potentially-important Stage II and III varieties actually existed. However, it was not until an experiment station was financed by the growers and established at Mt. Edgecumbe that these Stage II and III varieties from Java and India were introduced. From 1925 until 1945 the accomplishments of this station were entirely confined to the introduction of new disease-resistant Stage III varieties, mostly from Java and India.

The percentage of the South African crop consisting of these new varieties rose from 3.3 percent in 1933-34 to 95.5 percent in 1942-43, nine years later. An analysis of yield increases indicates that the new varieties introduced by 1945 outyielded the old Uba variety by about 27 percent.[7/]

These first N:Co varieties were bred in India but the selections for commercial planting were made in South Africa. By 1947 the experiment station had produced its first South African variety, N:Co. 310. We have already noted that this variety came to be commercially produced in four other countries, most notably in Taiwan (a rarity for a Stage IV cane variety), Table I.3. It, along with several additional N:Co varieties, occupied 78 percent of the planted acreage in South Africa by 1960, Table I.2. A yield comparison over a five year period of the N:Co varieties with the Stage III varieties from India and Java, which they substantially replaced, showed a 28 percent advantage for the locally-bred canes.[8/]

The South African experience with respect to the international transmission of the Stage II and III varieties (especially from Java and India) was repeated in most other cane-producing countries which had not developed Stage II and III varieties. The experiment stations in Queensland, Puerto Rico, Taiwan, Mauritius and several other countries were instrumental in the testing and introduction of these varieties into their local economies. The exhaustive collection and testing of varieties from other countries also served to provide a basis for the development of breeding programs in these newer stations.

In more recent years the Stage IV varieties have dominated production in most countries. A limited number of these varieties are transferred to other countries. An important element of international transmission of technological change remains, however. Genetic materials in the form of newly-selected seedlings, collections of wild canes and parent stock varieties of proven merit are freely exchanged between stations. In addition, the technical knowledge regarding improved breeding techniques, superior genetic parent stock, and more efficient selection methods also is exchanged.

Intra-country Transmission of Varietal Changes

The South African case again is informative regarding the adoption of new varieties within a given sugar economy. The organization of the industry in South Africa is similar to the organization in a number of countries. Most planters have large acreages (200-1,000 acres) with substantial capital investment. Planters have highly-structured relationships with the processing mills and are well organized. One would expect an organization of planters which supports an experiment station to adopt new varieties developed by that station rather quickly. This appears to have been the case in South Africa and in most other countries. This rapid adoption is heightened by a sense of international competition in achieving comparative advantage in sugarcane production.

In South Africa the variety Co. 331 was introduced in 1946-47 and reached its highest proportion of planted acreage (25 percent) only eight years later. N:Co. 310 was introduced in 1948-49 and reached its maximum proportion of planted acreage (60 percent) nine years later. Given that the average age of old cane when ploughed out and replanted in South Africa is now six years, this would seem to be extremely rapid adoption. In fact, planters altered their usual cropping pattern in many cases by ploughing out old cane varieties earlier than usual in order to plant new varieties.

In Australia, each of the varieties, Q50, Pindar, Trojan, and P.O.J. 2878 reached a maximum proportion of planted acreage (25 percent) approximately 10 years after introduction. In Puerto Rico, BH 10-12, introduced in 1920, reached a maximum proportion of approximately 25 percent fifteen years later. However, PR 980, a locally-bred variety introduced in 1955, had reached a proportion of almost 50 percent only ten years later.

This rapid adoption of new varieties does not necessarily hold for all sectors of the sugar-producing economy. The Indian and native planters in South Africa produced yields only two thirds as high as the European planters' yields in 1959. The small holder planters in Java and other countries also have lower yields than the estate or plantation planters. This is not necessarily a consequence of slower adoption of new varieties. India, a country with many small growers, has also experienced relatively rapid adoption of varieties. For example, in 1960 varieties Co. 527 and Co. 449 accounted for 6 and 1 percent of the acreage of Andra Pradish. Seven years later the proportions were 14 and 8 percent, respectively. /18/

Effects on Sugar Trade

Table I.5 presents trade data for sugar. It should be noted that roughly 40 percent of the world's sugar production is from sugar beets. With the exception of limited trading of beet sugar between Eastern European countries, world trade figures reflect movements of cane sugar.

The beet sugar production is important in the trade picture because virtually every beet-producing country has instituted a tariff and/or quota system to protect the domestic beet industry. The cost of such protection is high and has increased in recent years because of the relatively more rapid technological advances in sugarcane production.

Much sugar is traded under specific agreements between cooperating countries. Prior to 1961 the largest importing country, the United States, imported the bulk of its needs from Cuba, the largest exporting country. Since 1961 this U.S. - Cuban trade has ceased. The United States has allocated Cuba's former quota to other countries. Cuba has shifted her exports to Communist - bloc countries. The United Kingdom, the world's second leading importer, also has agreements with several exporting countries.

From time to time, International Sugar Agreements have been negotiated among countries in an attempt to control trade and production. They have been only partially effective. The "free" world market for sugar often has been a residual "dumping" market, and price changes have been volatile.

The data in Table I.1 and I.5 suggest a relationship between changes in sugarcane yields and changes in quantities exported by the major exporting countries. Five exporting countries, South Africa, India, Australia, Argentina and Taiwan had yield increases ranging from 32.5 percent to 41 percent between the five-year 1948-52 average and the ten-year 1958-67 average. These five countries increased their average annual exports by 4,069,000 short tons of sugar in this period. This increase in exports was 103 percent of the 1950 average production in these countries.

A second group of six countries, Philippines, Brazil, Peru, Indonesia, Mauritius and the Dominican Republic experienced yield increases ranging from 10 to 20 percent in this period.[9/] Their average annual exports increased by 2,079,000 short tons, 44 percent of their 1950 average production. Only the Philippines had an export increase, (65 percent) of the order of magnitude of any of the five high-yield-increase countries. Cuba, on the other hand, experienced an actual yield decline for the same period and displayed an almost constant average export volume.[10/]

This evidence supports the contention that shifts in comparative advantage have been reflected in the world sugar trade. This relationship is apparent even though world sugar trade has been dominated by (1) inter-country agreements, (2) shifts in the position of competing crops, and (3) changes in the degree of protection offered domestic beet sugar industries.[11/]

The Benefits From Sugarcane Technological Change

The advances in productivity in the production of sugarcane have been rapid and valuable. However, the actual benefits are difficult to assess for each country. Presumably, each importing, non-producing country receives a straightforward benefit which can be seen as a fall in the real price of sugar or, more accurately, a downward shift in the supply schedule facing them. The supply schedule faced by domestic users is not allowed to shift in every importing country because of the protection offered domestic beet producers. Gains do occur in the form of higher import duty collections or higher prices to favored exporting countries.

To the producing countries, relative rates of technical change matter greatly. For many producing countries, a good crop alternative to sugarcane does not exist. Producer groups have been keenly aware of their competitive position with respect to world trade. This partially explains why sugarcane growers in almost every country have been willing to privately finance their own experiment stations.[12/]

An exporting country which experiences a relatively slow rate of technical change in production also will experience a reduction in the factor or resource payments it receives unless it has some agreement with an importing country to maintain the price it receives. The country which can achieve a rate of technical change which is faster than its competitors will increase its economic return to the factors and resources which it owns.

The development of sugarcane technology is interesting in that it differs in several important respects from the development of technology in other agricultural crops. First, the development of modern technology in this crop came relatively early. Much of it had occurred by the 1930's. The comparable developments in hybrid corn and wheat, for example, came somewhat later. However, some of the development in rice production took place at about the same time.

Second, the countries which made the first major contributions were not highly-developed countries. Clearly, India and Java were the two leading countries in the early stages of cane-breeding. Finally, the conditions for international transfer of technology were more favorable in sugarcane than in most other agricultural crops. The early Stage II varieties were transferred easily. New cultural practices were not required. Only information about the relative profitability of producing the new variety was needed.

Stage III varieties were more difficult to transfer because knowledge about specific disease resistance was required. Many new experiment stations (as well as the established stations) contributed to the transfer of these Stage III varieties. In South Africa, as we have seen, the introduction of Stage III varieties from other countries increased average yields by 27 percent. If one wished to attribute this yield increase to the experiment station efforts, a handsome return to such investment can be calculated.[13/]

It is difficult to determine the proper allocation of benefits in a case where the varieties were developed in one station, but another station was required for their adoption. Presumably, the second station simply has caused the varieties to be adopted earlier than otherwise, and a value could be placed on this.

The Stage IV cane-breeding activity is somewhat more straightforward in terms of the allocation of benefits. Each station typically produces varieties planted only in the region where the station is located. Shifts in the production function and supply curve do yield benefits to the producing country which can be attributed to the breeding effort of the local station.[14/]

An additional complication is added to the assessment of benefits when one considers the possibility that international transfer of technology means that an experiment station may not only shift the production and supply functions of its own economy, but the production and supply functions of other economies as well. Thus the export country's own demand function for exports will shift, probably to the left.

The Java case is an excellent example of this. The Java station was the leading generator of new varieties from 1900 to 1930. During most of this period, Java was enjoying an increasing relative advantage over other producing countries, including India, which was also a leading generator of new varieties, but whose own varieties were often better suited to other tropical countries than to northern India where much of her production was located. A "technology gap" had been created and reached its widest point around 1930. Yet Java was particularly susceptible to the demand effect of this international transmission of her own varieties because of her position as the major free-market supplier. The demand for sugar declined in the early depresssion years and Java bore the brunt of the reduction in world trade. Since then, the transmission of the Java (and other Stage II and III) varieties reduced the technological gap. A general "catching-up" phase has all but eliminated the gap today.

The benefits from the new varieties of sugarcane were not entirely confined to cane yield increases. In general, the introduction of stage II and III varieties resulted in a substantial improvement in the sugar content of the cane. Table I.6 presents some evidence for this assertion.

Table I.1.--Natural sugarcane yield and production averages for selected five-year periods

Country	1910-1914		1923-1924		1928-1932		1938-1942	
	Production[a]	Yield[b]	Production	Yield	Production	Yield	Production	Yield
1. Brazil	333		860		956		1,333	17.1
2. Cuba	2,287	14.5[e]	4,345	19.3	4,389	18.6	3,200	17.2
3. India	2,699[c]	11.3	3,563[c]	11.0	3,561[c]	12.4	5,508[c]	11.5
4. Mexico	163		175	30.2	235	20.5	398	22.4
5. Australia	216	17.3	409	16.8	450	16.9	746	20.3
6. Philippine Islands	294		502		968	20.4	1,146	22.6
7. Argentina	194	11.6	260	13.2	410	13.6	509	13.4[f]
8. Hawaii	567	40.7	614	43.3	951	60.1	935	65.1
9. United States	311	15.8	229	9.4	149	15.0	460	19.3
10. Taiwan	192	11.8	450	16.1	869	29.3	1,357	
11. South Africa	88		181	8.8	312	20.5	534	26.3
12. Puerto Rico	363		414	16.6	795	25.3	998	32.4
13. Peru	203	22.4	344	24.3	441	40.5	482	52.6
14. Indonesia	1,513	41.2	1,985	46.5	3,010	56.4	1,718	61.5
15. British West Indies[d]	218		231	9.6	348	24.0	502	17.6
16. Dominican Republic	105		231		419		484	19.0[g]
17. Mauritius	234	15.6	238	14.5	241	15.2	337	19.8
18. Egypt	67	18.8	93		123	35.0	188	

(continued)

Table I.1.--(continued)

Country	1948-1952 Production	1948-1952 Yield	1958-1962 Production	1958-1962 Yield	1963-1967 Production	1963-1967 Yield
1. Brazil	1,775	17.4	3,726	18.8	5,329	19.8
2. Cuba	6,378	17.0	6,030	17.0	4,950	16.2
3. India	1,548	13.1	3,364	15.3	4,515	20.8
4. Mexico	789	23.1	1,665	26.4	2,319	27.0
5. Australia	865	23.6	1,395	27.5	1,643 i/	36.2
6. Philippine Islands	912	20.3	1,626	26.7	1,584	19.3
7. Argentina	687	14.9	950	17.0	1,422	23.0
8. Hawaii	979	76.4	1,048	90.0	1,275	98.7
9. United States	517	19.5	707	24.5	1,104	25.3
10. Taiwan	683	27.3	931	33.7	1,100	38.6
11. South Africa	612	25.1	1,140	35.3	1,002	35.8
12. Puerto Rico	1,264	29.8	1,051	30.4	897	30.6
13. Peru	544	60.0	884	70.4	882	64.2
14. Indonesia	356	40.0	780	49.5	854	39.1
15. British West Indies d/	617	38.1	808	39.4	801	36.4
16. Dominican Republic	590		1,012	19.5 h/	800	22.5
17. Mauritius	490		535	24.6	732	24.0
18. Egypt	215	32.8	369	42.6	465	40.0

a/Production in thousands of short tons of 96 percent sugar

b/Yield in short tons of cane per acre

c/Expressed in short tons of low grade gur

d/Countries included are Antiqua, Barbados, British Guiana, Trinidad, Tobago, St. Christopher, St. Lucia, St. Vincent

e/ 1913-1914 only

f/ 1940-1942 only

g/ 1940 only

h/ 1960 only

i/ 1963 only

Source: *Yearbook of Agriculture*, USDA, U.S. Gov. Printing Office, Washington, various issues, 1925-35.
Agricultural Statistics, USDA, U.S. Gov. Printing Office, Washington, annual issues, 1936-66.
International Sugar Situation, USDA, Bureau of Statistics, Bulletin 30, 1904.
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Annual Report, Bureau of Sugar Experiment Stations, Queensland annual reports, 1900-64.
South African Sugar Yearbook, South African Sugar Journal, Durban, 1935, 1948-49, 1961-62.
International Yearbook of Agricultural Statistics, International Institute of Agriculture, Rome, various issues, 1910-46.
Indian Sugar Manual, The Sugar Technologist Assoc. of India, Kalyaupur, Kanpur, 1962, 1963-64.

Table I.2.--Percent of sugarcane acreage planted to varieties developed by the experiment station of selected countries and years, 1930-1965

Country	1930	1940	1945	1950	1955	1960	1965
				- percent -			
Queensland	20	20	33	54	83	85	85
Hawaii	50	65	82	100	100	100	100
South Africa	0	0	0	3	49	78	
Taiwan		32	46	56	10	4	42
Puerto Rico	0	9	12	10	3	35	50
Mauritius		8	53	98	93	78	
Louisiana	0	23	52	77	65	65	

Source: Annual Report, Bureau of Sugar Experiment Stations, Queensland, various issues, 1928-1964.

Proceedings of the Twelfth Congress, International Society of Sugarcane Technologists, New York, 1967. pp. 867, 1041.

Culture of Sugarcane for Sugar Production in Louisiana, USDA Agriculture Handbook 262, Washington, D. C., 1964.

Table I.3.--Important sugarcane varieties, 1940-1964

Variety	Station	Date bred	No. of countries where produced commercially	Importance as variety Production[a]	Importance as variety Rank	Importance as parent Production[a]	Importance as parent Rank	Importance as grandparent Production[a]	Importance as grandparent Rank
PoJ 2878	Java	1921	12	44.1	1	31.7	1	2.9	13
Co 290	India		7	14.7	2	7.4	7		
Co 213	India	1914	4	10.3	3	11.9	5	13.4	4
ML 318	Cuba	1930	1	10.0	4				
Pepe Cuca	Cuba	1930	1	10.0	5				
Co 331	India		3	8.1	6				
H 371933	Hawaii		3	7.2	7				
PoJ 2883	Java		4	7.1	8				
Co 419	India		3	6.6	9				
N Co 310	S. Africa		5	6.5	10				
Co 312	India		1	6.2	11	3.7	16		
BH 1012	Barbados	1910	4	4.8	12				
Co 313	India		1	4.6	13				
H 328560	Hawaii		3	4.6	14	8.6	6		
B 37161	Barbados		2	3.7	15				
Co 281	India		4	3.5	16	13.1	4		
Badilla	(New Guinea) Native variety		1	3.4	17				
H 443098	Hawaii		2	3.1	18				
F 108	Taiwan		1	2.7	19				
PoJ 2364	Java	1911				27.1	2	18.6	2
EK 28	Java	1911	1			26.0	3	18.6	3
Co 221	India	1918				7.3	8		
PoJ 213	Java	1893				6.8	9	9.2	6
SC 124	Barbados	1912				6.4	10		
Co 244	India					5.4	11	2.9	14
Co 291	India					5.1	12	3.7	9
Co 421	India					4.5	13		
PoJ 2725	Java	1917				4.5	14		

(continued)

Table I.3.--(continued)

Variety	Station	Date bred	No. of countries where produced commercially	Importance as variety Production[a]	Rank	as parent Production[a]	Rank	as grandparent Production[a]	Rank
Co 214	India	1914				4.0	15		
Co 270	India					3.0	17		
B 6835	Barbados					2.5	18	3.6	10
B 4578	Barbados					2.4	19	3.6	11
CP 1165	U.S.					2.2	20		
PoJ 100	Java							26.5	1
EK 2	Java							11.6	5
Co 206	India							6.6	7
D-74	Demarara							3.7	8
Co 205	India							3.3	12
Co 285	India							2.6	15
Striped	Mauritius - native							2.3	16
M-4600	Mauritius							2.0	17

[a]Total production in millions of short tons of 96 percent sugar, 1940-1964.

Source: Yearbook of Agriculture, USDA, U.S. Government Printing Office, Washington, 1936, pp. 561-624.
Proceedings of the Twelfth Congress, International Society of Sugarcane Technologists, New York, 1967, pp. 844-854.
Agricultural Statistics, USDA, U.S. Government Printing Office, Washington, various issues.
J. T. Rao and Vijayalakshmi, Improved Canes in Cultivation, The Indian Central Sugarcane Committee, New Delhi, 1967.

Table I.4.--Varietal production of various sugarcane experiment stations, 1940-1964

Experiment station	Varieties		Variety parents		Variety grandparents	
	Production[a]	Rank	Production[a]	Rank	Production[a]	Rank
			- mil metric tons -			
Coimbatore, India	64.7	1	75.4	2	53.8	3
Java (P.O.J.)	63.4	2	102.3	1	113.6	1
Hawaii	24.9	3	18.1	4	16.8	4
Cuba	20.4	4				
Barbados, B.W.I.	10.8	5	18.8	3	59.4	2
Canal Point, Fla.	10.3	6	4.5	6	4.2	7
Queensland	9.1	7	3.3	7		
South Africa	7.3	8	.3	10	.3	9
Taiwan	4.2	9				
Mauritius	4.2	10	1.7	9	6.0	6
Brazil	3.9	11	1.8	8	1.8	8
British Honduras	3.9	12				
Puerto Rico	3.8	13				
Peru	2.2	14				
British Guiana	.2	15	8.5	5	12.2	5

a/Total production of 96 percent sugar, 1940-1964.

Source: Yearbook of Agriculture, USDA, U.S. Government Printing Office, Washington, 1936, pp. 561-624.
Proceedings of the Twelfth Congress, International Society of Sugarcane Technologists, New York, 1967, pp. 844-854.
Agricultural Statistics, USDA, U.S. Government Printing Office, Washington, various issues.

Table I.5.--Net exports and imports of 96 percent sugar by countries, selected years[a]

Country	1909-1913 (average)	1922-1923 (average)	1928-1931 (average)	1937-1939 (average)	1948-1952 (average)	1958-1962 (average)	1963-1967 (average)
				- thousand short tons -			
Current exporters							
Cuba	2,009	4,725	3,885	2,947	5,790	6,102	5,859
Australia	- 76	-----	24	477	381	910	1,317
Philippine Islands	175	345	831	960	561	1,106	1,195
Taiwan	5	- 20	-----	56	413	850	922
Brazil	38	223	40	14	109	766	841
Mauritius	226	285	234	331	465	524	638
Dominican Republic	92	188	388	457	506	878	576
Jamaica	14	42	49	114	220	381	482
Peru	146	306	366	306	317	542	453
South Africa	- 29	23	138	240	58	333	330
India	- 689	- 518[b]	- 788	- 64	- 684	167	281
Indonesia	438	2,066	2,296	1,318	13	43	165
Argentina	- 52	- 54	9	31	-1,626	59	71
Current importers							
U.S.A.	-2,081	-3,787	-2,982	-2,943	-3,521	-4,583	-3,853
U.K.	- 821	-1,362	-2,062	-2,151	-1,574	-2,141	-2,036
Japan	- 117	- 162	- 43	94	- 554	-1,429	-1,897
U.S.S.R.						-1,262	-1,723
Canada	- 297	- 100	- 451	- 485	- 605	- 748	- 904
Malaysia	-----	-----	- 100	- 138	- 170	- 243	- 360
Algeria	- 38	- 41	- 77	- 71	- 133	- 245	- 287
New Zealand	- 50	- 73	- 86	- 90	- 108	- 135	- 161

a/Exports are positive numbers; imports are negative.

b/1924.

Source: Yearbook of Agriculture, USDA, U.S. Government Printing Office, Washington, annual vols.1925-35. Agricultural Statistics, USDA. U.S. Government Printing Office, Washington, annual vols.1936-66. International Yearbook of Agricultural Statistics, International Institute of Agriculture, Rome, various volumes 1910-46.

Table I.6.--Tons of sugarcane needed per ton of sugar, five-year averages, selected years

Country	1903-1907	1913-1917	1923-1927	1933-1937	1943-1947	1953-1957	1963-1967
India				8.6	8.0	8.1	
Philippines			8.6	8.6	8.3	8.9	9.0
Queensland (Australia)	9.1	8.6	7.5	7.0	7.1	7.4	7.0[a/]
United States		14.3	16.0	12.5	10.9	11.5	11.1[b/]
Puerto Rico		9.1	9.1	8.2	7.4	8.4	9.8
Hawaii		7.9	8.2	8.8	9.0	8.7	8.8[c/]
Cuba			8.7	8.3	8.0	7.9	
South Africa			10.1	9.5	8.6	8.8	

a/1963 only.

b/1960 only.

c/1962 only.

Source: Annual Report, Bureau of Sugar Experiment Stations, Queensland, annual reports 1900-1964.
International Sugar Situation, USDA Bureau of Statistics Bulletin 30, 1904.
Sugar Statistics and Data, Vol. 1, revised, USDA Statistical Bulletin 214, 1957.
Agricultural Statistics, USDA, U.S. Gov. Printing Office, Washington, D. C., various issues.
Indian Sugar Manual, The Sugar Technologists' Association of India, Kalyanpur, Kanpur, 1962.
Proceedings of the Ninth Congress, Vol. I, International Society of Sugarcane Technologists, New Delhi, 1956.
South African Sugar Yearbook, South African Sugar Journal, Durban, 1961-1962.

II. Bananas[15/]

One of the most dramatic episodes in the long history of banana production and trade in the Central American tropics has been the development and international diffusion of new technologies in response to devastating inroads of the Panama disease in bananas. In the 20-year period following World War II, two major technological developments stand out. The first is the selection, diffusion, and adoption of disease-resistant banana varieties. The second is the invention and application of processing and handling techniques specifically designed to accommodate the physical and economic attributes of the new varieties.

The economic impact of this episode on other exporting nations whose banana farms and plantations were not ravaged by Panama disease illustrates side effects that can occur when important technological change directly affects only some producers of an internationally-traded commodity.

The Post-War Setting

During World War II, international trade in bananas shrunk drastically because of the extreme shortage of refrigerated, ocean-going ships. But as shipping became available after the war, banana production and exports rebounded quickly, attaining prewar levels by the 1948-52 period, Table II.1.

Banana exports from Central America dominated the world trade picture, accounting for about half the total in 1948-52. Most of these

Central American shipments went to the United States and Canada. (At this time the United States purchased about two-thirds of all the world's banana exports.) But largely because of rising banana production in Ecuador, South American exports surpassed their prewar levels in the 1948-52 period.

International banana prices were relatively high in this period, and the stage seemed to be set for orderly and profitable growth in the world banana market. United Fruit Company and Standard Fruit and Steamship Company, the two major fully-integrated banana producing and marketing firms operating in the American tropics, resumed activities on much the same basis as before the war by re-activating and adding to their war-idled resources. These two U.S.-based firms had operated plantations, export facilities, and a host of community services (roads, railroads, schools, hospitals, etc.) in Central America since the early 1900's. The United Fruit Company was by far the larger of the two firms. Their combined banana output accounted for all but a small portion of Central American production.[16/] Together, United Fruit and Standard Fruit held some 90 to 95 percent of the U.S. import market during the 1948-52 period.

Over the years, these two companies, especially United Fruit, had conducted long-range, research programs on banana production and marketing technology. The financing of these continuing programs has varied over time as circumstances in the industry have changed. But the research done by these firms is both basic and applied. In fact, much of the world's scientific and practical knowledge about bananas has been generated by these privately-sponsored research programs.

Panama Disease

Bananas are subject to a host of deadly plant diseases. Although most now can be controlled, several diseases, at one time or another, have threatened the very existence of large areas of commercial farms and plantations. For example, in the 1930's the rapid spread of sigatoka disease, a wind-borne leaf destroying fungus, decimated large banana tracts in Central America. It threatened to wipe out the whole industry. However, frantic research mainly by United Fruit Company technicians uncovered an effective treatment based on periodic applications of Bordeaux mixture suspended in water. /25, p. 154./ By 1939, most large banana plantations were equipped with elaborate, permanent networks of pipes and spray facilities.[17/] In Mexico, where large-scale sigatoka control was not undertaken partly because of the small size of individual banana farms, this disease virtually killed off the banana industry by 1950.

But no really effective treatment has yet been found for Panama disease. This soil-borne fungus (fusarium wilt) invades the soil, attacks the root system of the susceptible plant, and causes a breakdown in the vascular flow of water and nutrients. /37, Chap. 13/ The result is stunting and eventual destruction of the infected plant. Though Panama disease spreads more slowly than sigatoka, the organism remains indefinitely in the soil, rendering infected areas useless for future production of susceptible varieties.

Panama disease does not attack all varieties of bananas; some are highly resistant. However, the Gros Michel variety is quite susceptible.

This variety is the traditional commercial banana of Central and South America. Its handling, ripening, and flavor qualities have long been prized by banana men. But it has not been possible to develop a Gros Michel banana with disease resistance. Because the banana is, botanically, a giant herb growing from an underground rhizome, cross breeding, and other known techniques of producing new varieties having selected characteristics of existing varieties are very difficult to apply.

Efforts to "purify" infected acreage by flooding it with water for periods up to a year have proven only temporarily effective. This technique, known as flood fallowing, is very costly and provides immunity from re-infection from only one to five years, depending on soil type and other environmental factors.

Panama disease was identified and widely-known in tropical America as early as 1900. Its spread was gradual but inexorable throughout the region's banana lands. By World War II, only a few areas, notably Ecuador and Colombia, seemed relatively free of the disease. Since no effective treatment could be found, the spread of the disease was partially offset by abandonment of infected areas. New plantings were then established on previously uncultivated sites. This was a workable practice until the post-World War II period when banana production began to exceed pre-war levels.

By the 1948-52 period, Panama disease was pervasive, especially in Central America. Relocating and replanting whole farms and plantations had become prohibitively costly. In addition, good disease-free banana land, accessible to existing handling and shipping facilities, was becoming very scarce. United Fruit Company has estimated that since 1900, some 925 thousand acres of banana land has been abandoned mostly because of Panama disease. This averages about 14 thousand acres per year. These average annual abandonments amounted to about 10 percent of United Fruit's owned and controlled banana acreage in the early 1950's. For instance, United Fruit's Quepos Division in Costa Rica had about 25 thousand acres in banana production in 1947. By 1956, Panama disease had wiped out all production.

Officials of both United Fruit and Standard Fruit were extremely reluctant to consider abandoning the Gros Michel banana even though the ravages of Panama disease had reached a critical stage, and research on feasible control methods was not especially promising.

The Critical Stage

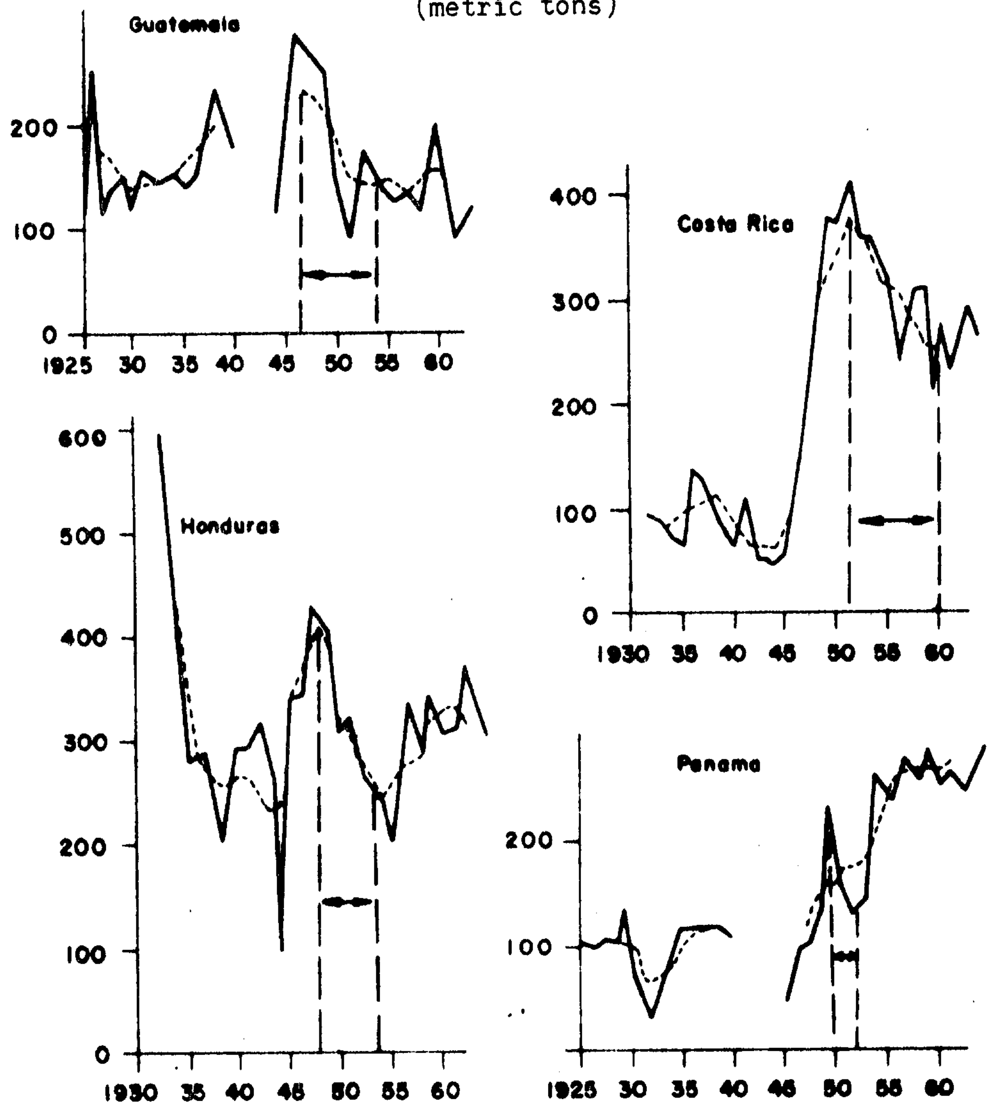
We can consider the 1948-52 period as the start of the critical stage in the Central American banana industry's confrontation with Panama disease. From this period into the middle and late 1950's the area's banana production and exports dropped. The data in Table II.2 indicate the downward slide in acreage from 1948-52 to 1958-62. The stagnation in Central American exports in this period is indicated by the data in Table II.1. Abandonments mainly due to Panama disease exceeded replantings in three of the four major producing countries; Guatemala, Honduras, and Costa Rica. Only Panama showed increased acreage. There, a 12 thousand acre flood fallow and replanting program was begun by United Fruit Company in 1950. This experiment was designed to revive one of the company's plantations which had lain idle since Panama disease wiped out production in 1936.

The charts in figure 1 show banana exports for these four nations annually and as a five year moving average for about 30 years.[18/] The drop exports that can be attributed mainly to inroads of Panama disease is shown between the vertical dotted lines. Even in Panama, where the production and export trend was generally increasing in the 1950's, a major export drop occurred between 1950 and 1952 as the flood fallow and replanting program got underway.

As Central American production faltered in the 1950's, exports from other sources expanded substantially, Table II.1 Banana exports from Ecuador and Colombia in South America are most relevant in this expansion. Almost all other major banana exporters operate under the protection of preferential arrangements with major importers (e.g., Jamaica and Windward Island with the United Kingdom, Guadeloupe and Martinique with France, the Canary Islands with the Spanish mainland). The dramatic surge of Ecuadorian and Colombian banana shipments to replace lagging Central American exports is shown in figure 2.

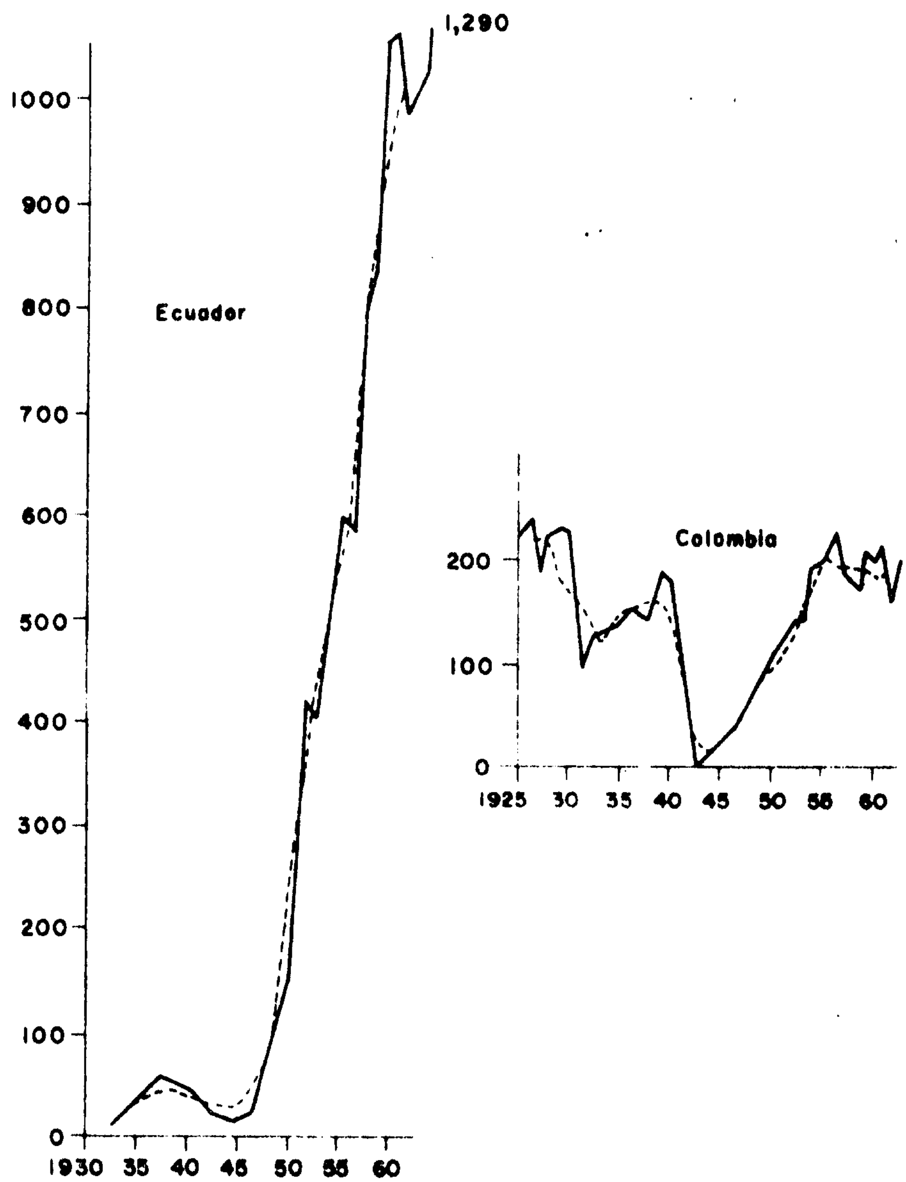
As mentioned previously, both Ecuador and Colombia produced mainly the Gros Michel variety, but were relatively free of Panama disease in this period. Colombian bananas were shipped mainly to Western Europe, and up to two-thirds of Ecuador's exports came to the United States where, by 1959, they accounted for over 40 percent of all U.S. banana imports. Ecuadorian bananas easily filled the gap left by the dwindling supplies and rising costs of Central American bananas. Growing markets,

Figure 1: Volume of banana exports from four Central American Countries; annually and five-year moving average, 1925-1964
(metric tons)



Source: Food and Agriculture Organization, United Nations

Figure 2: Volume of banana exports from Ecuador and Columbia; annually and five-year moving averages; 1925-64
(metric tons)



Source: Food and Agriculture Organization, United Nations.

abundant land, and government encouragement fueled this tremendous output growth. The major banana companies, United Fruit and Standard Fruit, participated in this Ecuadorian expansion mainly as shipping and marketing agents -- United Fruit's single small producing division in that country was expropriated in the early 1960's. Since then, the Ecuadorian government has effectively discouraged the formation of additional foreign-controlled plantations.

A number of smaller exporting and marketing firms, operating with Ecuadorian supplies, flourished during this period. As a result, the combined U.S. market share of the two integrated, producing-marketing companies dropped to about 70 percent in 1959. Ecuadorian banana quality was uneven, seasonal variations in output were sharp. In addition, an export tax was levied, and shipping charges exceeded those for Central American Fruit. Yet the demand for Ecuadorian bananas surged ahead as the Central American producers struggled with Panama disease.

Given the state of the arts during the early portion of this critical stage, it seemed likely that, barring a massive Panama disease outbreak, Ecuador soon might corner the relatively open banana markets in North America,,Western Europe, and elsewhere. Without a major cost-reducing shift in banana production technology, the invested capital, land resources, production knowledge, and quality-control skill of the integrated companies in Central America might become virtually worthless. Moreover, an important source of vital foreign exchange and tax revenue for the four Central American nations would wither.[19/] The companies and their host governments were in trouble with bananas, and they knew it.

Resistant Varieties: Selection and Adoption

Although the Central American trade was built on Gros Michel bananas, a number of Panama-resistant varieties were known to scientists and grown commercially in other areas. The banana industries of Jamaica, French West Indies, Canary Islands, Australia, and others, were based on resistant varieties belonging to the Cavendish group. These varieties had been shunned by the major producing companies because of supposedly lower yields, poorer handling and ripening qualities, and somewhat different management requirements. Another important factor, no doubt, was simply internal resistance to change within the companies. The firms' producing, shipping and marketing divisions knew, with precision, how to grow, transport, and merchandise Gros Michel. Much would have to be relearned if new varieties were adopted.

Resistance to a variety switch eroded faster in the smaller Standard Fruit and Steamship Company. A major management change in 1953 and the existence of smaller disease-free land reserves under company control in producing areas contributed to this attitude change. By 1957, Standard had planted 14-15 thousand acres in bananas of the Cavendish group. These varieties were selected by researchers from those available in the Carribbean, Africa, and elsewhere. Over time, Standard Fruit researchers focused their attention on one of these varieties, the Giant Cavendish.

In 1960, United Fruit Company botanists began to look seriously at a disease-resistant variety called the Valery which was being grown on the firm's experimental farm in Honduras. This plant has been collected originally in Vietnam by a company expedition several years earlier. In 1962 a major company decision was made to move rapidly into Valery plantings. Even with the problems of multiplying and distributing new seed stock, virtually all production by Standard and the majority of United's was in disease-resistant varieties by 1965.

Once begun, the adoption and diffusion of Giant Cavendish and Valery bananas spread quickly. However, this pattern of development and rapid diffusion of disease-resistant varieties should not be interpreted as a clear indication that rapid technical change in tropical agriculture is most likely in sectors or industries dominated by large plantations and vertically-integrated firms capable of internal research and development. The diffusion process in the Central American banana case was indeed rapid. But the long delay by the managements of the major companies in selecting, adopting, and marketing resistant strains was nearly disasterous for them. On the other hand, the shift to Cavendish type bananas already had occurred in the Western Indian banana industries of Jamaica, Windward Islands, Guadeloupe -- Martinique -- areas where small holders and public research facilities predominate.

Diffusion of Giant Cavendish and Valery bananas in Central America was spurred not only by the monolithic decision structures of the two large firms but because of several unexpected advantages with the new fruit which were not apparent at first. As the new varieties were put into commercial production in the Central American lowlands -- probably the world's best overall banana-growing environment -- per acre yields were higher than anticipated and even higher than Gros Michel yields.[20/]

Heavier bunches and higher planting densities contributed to this yield advantage. Because the new varieties are lower-growing, the constant danger of losses due to wind-caused "blow-downs" is reduced below that for the lankier Gros Michel plants.[21/] Though it had always been generally assumed that the Gros Michel was the best-tasting banana in world commerce, some test results in the United States in the early 1960's showed that properly-handled and properly ripened Valery bananas were distinctly superior in flavor and aroma to Gros Michel.

There was a major problem with the new varieties about which the skeptics had been correct. Bananas of the Cavendish group were not well suited to the commercial methods of handling and shipping then in use. In the 1950's and early 1960's bananas from Central and South America were still handled as whole stems (bunches) from the moment of harvest until ripening was completed in the importing country. Individual stems, protected by only a thin plastic film bag, were handled up to a dozen separate times en route to the wholesale fruit dealer. The Gros Michel is well-suited to this system. However, the individual fingers of fruit on the new varieties are more easily bruised in the green stage than with Gros Michel. Furthermore, the banana clusters on the new varieties do not lie as close to the stem's center stalk as on the Gros Michel. Hence, they are more easily damaged. With all the handling of exposed stems built into traditional techniques, quality control with the new varieties was very difficult in comparison with the established Gros Michel.

When the first yields of the new varieties were coming onto the North American market, Standard Fruit Company encountered severe quality problems. Outright rejections on arrival were quite high. In addition, prices for the new variety fruit were discounted by wholesale buyers because many banana quality problems do not show up until the fruit is fully ripened and ready for retail merchandising.[22/] Standard's response to these quality control problems probably saved the company and set off a market-induced technological shift that is revolutioninzing banana handling in virtually all international markets.

Tropical Boxing

During the reign of the Gros Michel in Central and South America, virtually all shipments to North American and European markets were cargoes of stem fruit. Bananas remained on the stem until the ripening process was completed in local markets by specialized ripeners, wholesale fruit jobbers, and chain stores. These establishments, of which there were about 1,600 in the United States in 1955, also cut the individual clusters (hands) from the stem, packed them in returnable cartons, and merchandised them to retailers. So in addition to ripening and retail distribution, these firms performed an important sorting, grading, and packaging function.

In the early 1960's, Standard Fruit began to experiment with the system of cutting, washing, sorting, and packaging individual clusters into 40-pound labeled cardboard boxes in the tropics near their production and shipping facilities. The boxed fruit was then shipped to wholesale buyers in the importing country. Under this system, ripeners in the importing country relinquished the cutting and packing function and part or all of the sorting and grading function. They retained the ripening and retail distribution functions. Acceptance of this innovation was unexpectedly rapid in many parts of the U.S. market.

Boxed bananas are more easily handled with typical rail, truck, and warehouse machiner, and, in boxes, the new variety fruit is less likely to be bruised. Like all other firms in the food marketing sector, ripeners and jobbers were under severe economic pressure to become larger and more efficient. With boxed bananas, they found that they could reduce per unit costs by eliminating a series of labor-intensive processes and increase the volumes handled. In addition, retailers were pleased with the non-returnable, one-way cardboard carton. From the producing company's viewpoint, more fruit could be salvaged all along the way since, under the old system, whole stems had to be discarded if a single cluster was damaged or had become prematurely yellow. Moreover, the specialized loading and unloading equipment at the seaports was still usable, with some modification, for boxed fruit. Further experience has shown that boxed bananas can be stowed more efficiently in refrigerated cargo ships, and elimination of the center stalk which is about 15 percent of the weight of stem bananas reduces the shipping costs per unit of usable fruit.

The demand by wholesalers for boxed bananas grew so rapidly in the United States that Unit Fruit Company, which was still shipping Gros Michel in 1962, was forced to develop its own tropic boxing facilities even before its Valery production began. Smaller independent importers, buying on the Ecuadorian market, began to establish boxing facilities in and near the producing regions in order to supply their U.S. customers with boxed fruit, even though their bananas were also Gros Michel variety. In a matter of only four years, boxed bananas went from an insignificant portion of the U.S. market to a majority of all imports, Table II.3.

The trend toward tropic boxing of export fruit is being accelerated in Ecuador. In response to new inroads of Panama disease in Gros Michel plantings, the Ecuadorian government has prohibited new plantings of this susceptible variety. [43, p. 21] Only varieties from the Cavendish group may be used for new farms or for replanting existing farms.

Standard Fruit Company adopted the tropical boxing technology in order to offset quality and handling problems stemming from its earlier decision to adopt the disease-resistant variety. United Fruit and the others adopted the boxing technology much earlier than they would have had to on purely technical grounds. The economic impact of the boxing technology on retail and wholesale channels required Standard Fruit's competitors to begin tropic boxing in order to maintain their previous market position. Several intermediate production processes, namely cutting, sorting, and boxing were shifted from the developed importing nation to the less-developed producing and exporting nations. In addition, new box-making plants are operating or are being established in Central America and Ecuador.

Economic Impacts

An economist looking at the impact of the disease-resistant varieties in Central America could argue that, as Panama disease spread through the region, the production function for bananas based on traditional inputs shifted slowly but surely downward. Output per unit of the usual inputs eroded at all levels of input application. The main objective of early decisions to adopt new varieties seems to have been to halt this erosion of the function and to stabilize it, even if stabilization was achieved at lower output levels than with Gros Michel. But as the resistant varieties were adopted in the lush Central American banana zone, experience suggested that the production function might be restored to pre-disease levels and perhaps even beyond them. The extent of this shift is not yet fully known. However, it seems likely that the adoption of new varieties will result in a net increase in the production function for Central American bananas as compared with disease-free Gros Michel output relationships.

The erosion of banana production relationships in Central America throughout the 1950's no doubt strengthened Ecuador's comparative advantage in banana production and export. This shift in comparative advantage was accelerated by deteriorating production relationships and prices for Ecuadorian cacao and by slow growth in that nation's coffee-producing industry. [46, Chap. 2.] Much of the banana boom in Ecuador during this period can be attributed to this alteration in comparative advantage vis-a-vis Central America. Adoption of new varieties has apparently halted this trend and, in fact, may be instrumental in restoring Central America to its pre-eminent position in the world banana trade.

Tropical boxing of bananas was undertaken initially to facilitate the shift to new varieties. The main objective was to maintain quality and reduce waste and transit loss. In effect, the boxing of bananas near the production area was at first a method of sustaining the production function, in terms of output of marketable fruit, at levels higher than otherwise would have been the case. The rapid adoption of this new technique in the producing areas where Gros Michel still ruled indicates that it is a net cost-reducing procedure for bananas moving into the relatively sophisticated marketing channels of North America and Western Europe.

The economic impact of tropical boxing is to shift the locus of several intermediate handling and processing functions from the marketing system of the importing nation to the tropical producing areas. Furthermore, it alters the nature of the actual product moving in international commerce from an essentially unprocessed primary product to a commodity which is substantially closer to the final product sold to consumers.

Some calculations for 1963, when stem and boxed bananas shared the U.S. market about equally, indicate that on an equivalent basis, in terms of usable fruit, boxed banana import prices received by major importers were about 13 percent higher than stem prices. About $1.00 per hundredweight of the approximately $10.00 of value added to boxed bananas from harvest to retail was transferred from establishments in the U.S. to establishments in producing areas.[23/] Though this is only a rough approximation, it does indicate that, in terms of foreign exchange earnings and jobs, tropical boxing is a significant international shift in handling technology.

The development of box-making and assembly plants in the producing areas, though still in its early stages, has and can be expected to increase employment and economic growth in those areas. New capital for banana carton factories in Central and South America ran above $50 million in the 1960-66 period. This added industrial activity is a direct result of the adoption and diffusion of the banana boxing technology.

It is clear that the resurgence of the Central American banana industry in response to these two major innovations has slowed down and altered the growth and development of the Ecuadorian industry. The export data illustrated in figure 2 indicate this began to occur in the early 1960's. A slow-down in export volume growth and continued downward pressure on world prices have resulted in a stagnation in Ecuadorian banana export earnings since about 1963. Banana exports and earnings for Colombia, the other major South American supplier, continue to show only slow growth as Central American boxed bananas become more and more competitive in the European markets which have been Colombia's major outlets.

The data in Table II.4 show the exchange earnings and relative importance of banana exports for Central America and Ecuador in three periods: 1955-57, 1959-61, and 1964-66. The growth in other Ecuadorian export industries has reduced that nation's dependence on bananas somewhat since the peak period in 1959-61 and has helped to offset the shift of comparative advantage in bananas back to Central America. Banana earnings in the 1960's are generally increasing for all the major Central American exporters except Guatemala. However, some new Valery plantings by United Fruit Company in Guatemala are beginning to produce marketable fruit. They will partially offset previous Panama-disease abandonments.

Dependence upon bananas for foreign exchange, while still extremely important for several of these nations, especially Ecuador, Panama, and Honduras, has declined for all since 1959-61 and for all but Ecuador since 1955-57.

It appears that much of the future growth in the production and boxing of bananas will be focused in Honduras, Panama and Costa Rica. These nations seem to provide the best overall environment for the production of disease-resistant varieties and the packing and shipping of boxed bananas to world markets.[24/] Both United Fruit and Standard Fruit are engaged in major production-expanding programs with disease-resistant varieties in Honduras. United Fruit, the only major exporter of Panamanian bananas, is expanding its Valery output on fully-owned plantations. In addition, United has been relatively successful with an expanding associate producer program. Associate producers grow bananas under contract with United Fruit Company. They receive basic services, facilities, and credit from the company, but must follow specified production practices laid out by the company. Substantial expansion of production in Costa Rica is being planned, especially by Standard.

Banana prices in several major importing nations have been drifting downward since the late 1950's. Retail prices in the United States, Canada, and West Germany have dropped about 10 percent since 1958; "real" prices of course have dropped further. /42, p. 22/ /41, p. 8/ Increased supplies due to the new varieties and the adoption of tropical boxing have intensified this long-run tendency for supplies to increase faster than demand, and at least part of these price declines can be attributed to technological changes. Measuring the price impact of these changes is difficult, but perhaps the following is suggestive of the magnitudes.

Between 1965 and 1970, FAO has projected that world banana supplies will increase about 40 percent. /26/ Approximately one third of this increase will come from Central America. If it is assumed that Central American production would remain constant (or possibly decline) in the absence of the technical innovations discussed here, then the effect of these additional supplies on international banana prices is an approximate measure of the price impact of technical change in this area. It is only an approximation, of course, and probably an overestimation since export supplies from other sources, principally Ecuador, probably would have expanded faster than they actually will. In any case, the additional supplies from Central America in the last half of the 1960's will exert a downward pressure on retail prices approximately equivalent to 20 percent of 1965-66 levels. That is, in the absence of any expansion in Central America and assuming all other export availabilities remain as projected, then retail banana prices in world markets would average in 1970 some 10 percent below 1965-66 levels. When the projected increase in Central American supplies is added, then average retail prices some 30 percent below 1965-66 levels are required to balance amounts demanded with projected export availabilities. /26, table 4/ Any supply response to these lower prices naturally would offset at least some of this indicated downward pressure on retail prices. In addition, it is likely that consumers will benefit not only from lower prices but also because average banana quality can be expected to increase with increased tropical boxing in most markets.

As in the past, economists and historians will continue to debate the role and contribution of the banana industry to the growth and development of tropical America. Their analyses will have to encompass the long-run impacts of the diffusion and adoption of these two, interconnected technological innovations.

Table II.1.--World exports of bananas from South America, Central America, and the Rest of the World; five-year averages, 1935-1939 to 1963-1967

Region	1935-1939	1948-1952	1953-1957	1958-1962	1963-1967[a]
			- thousand metric tons -		
Central America[b]	1,130.2	1,157.9	1,120.1	1,227.8	1,401.7
South America[c]	425.4	532.8	974.8	1,424.4	1,739.6
Rest of the World	746.4	640.6	953.5	1,328.0	1,781.9
TOTAL	2,302.0	2,331.3	3,048.4	3,980.2	4,923.2

a/Includes preliminary data for 1967,.

b/Costa Rica, Dominican Republic, Guatemala, Honduras, Mexico, Nicaragua, Panama.

c/Ecuador, Colombia, Brazil.

Source: Food and Agriculture Organization, United Nations; (CCP Study Group on Bananas) Foreign Agriculture Circular, FDAP-1-67, FAS, USDA, October 1967.

Table II.2.--Acreages of exportable bananas in Central America; five-year averages 1948-1962[a]

Country	1948-1962	1953-1957	1958-1962
		- thousand acres -	
Guatemala	46.7	39.3	31.3
Honduras	55.8	53.5	43.5
Costa Rica	42.8	39.0	30.6
Panama	19.2	26.0	30.8

[a]Major companies and their associated growers only.

Source: Data supplied by major fruit companies.

Table II.3.--Percentage of U.S. imports of bananas arriving as boxed fruit, 1960-1966

Year	Percent in boxes
1960	2
1961	15
1962	30
1963	50
1964	85
1965	96
1966	99

Source: Estimated from data supplied by major importers.

Table II.4.--Value of banana exports and percent of total exports accounted for by bananas in four Central American countries and Ecuador; 1955, 1961, 1966

Country	Annual average 1955-1957	1959-1961	1964 1966
Costa Rica			
Banana exports (mil dollars)	26.1	20.1	28.6
Percent of total exports	34	25	24
Guatemala			
Banana exports (mil dollars)	15.5	15.3	6.5
Percent of total exports	13	14	3
Honduras			
Banana exports (mil dollars)	34.0	31.4	53.1
Percent of total exports	54	46	44
Panama			
Banana exports (mil dollars)	24.3	20.6	37.8
Percent of total exports	72	67	48
Ecuador			
Banana exports (mil dollars)	63.4	86.4	90.1
Percent of total exports	50	62	52

Source: International Financial Statistics, International Monetary Fund, Vols. 15, 17, and 21, and U.S. Department of Agriculture, Foreign Agriculture Service.

III. Rice[25/]

In this section an attempt is made to analyze the complex set of technical and economic interactions associated with (1) the diffusion of Japanese rice production technology to Taiwan and Korea, (2) the impact of productivity growth in rice production on rice trade between Japan and Taiwan and Korea, and (3) the impact of rice imports from these two colonial areas on rice prices and production in metropolitan Japan. Specifically, we will test two hypothesis advanced by several Japanese scholars. The first is that the transfer of rice production technology from Japan to Taiwan and Korea was responsible for the expansion of exports from the colonial areas to metropolitan Japan. The second is that these exports in turn depressed rice prices and dampened the growth of productivity and farm income in metropolitan Japan.[26/]

An alternative hypothesis which might be advanced is that the technical potential, in the form of biological and chemical innovations, for continued rapid technical advance in Japanese agriculture had not yet been created during the interwar period. This hypothesis apparently has not been seriously examined in Japan.

Output and Productivity Growth in Japanese Agriculture

The rate of output and productivity growth in Japanese agriculture has varied widely during the 100 years of "modernization" following the start of the Meiji period in 1968. Four main periods, sometimes called "technical epochs", are frequently identified, Table III.1.

The first is a period of rapid growth in output and productivity that ended during the 1920's. This was followed by a period of slower growth during the interwar period. The third is a period of decline and recovery associated with World War II. A fourth period of explosive growth in productivity began in the late 1940's or early 1950's. [15, 20, 31, 35, 47]

Output and productivity trends both for rice and for the total agricultural sector appear to have followed the same general pattern, reflecting the dominant role of rice in the agricultural economy.[27] The growth in output during the first technical "epoch" was achieved through a combination of increases in land inputs and growth of land productivity. Yield increases (land productivity) accounted for approximately two-thirds of the increase. Yield increases were achieved primarily through intensification of the "traditional" biological technology; that is, through (1) improved crop husbandry, including more intensive use of labor, (2) increases in the application of organic sources of plant nutrients (3) application of pre-Mendelian methods of crop improvement -- primarily through selection rather than breeding, and (4) through land improvement projects -- principally the replatting of paddy fields and improvement of water delivery and drainage systems. [31; pp. 388-409]

Institutions for the rapid diffusion of superior varieties and cultural practices from the best farmers and regions were developed during the 1880's. This effort was complemented by the development of prefactural (local) experiment stations in the 1890's. By the end of the period the research effort was increasingly focused on the development of a "fertilizer-consuming rice culture". This involved the development of rice varieties with shorter stems and more tillers. The application of the more intensive rice production technology was facilitated by small-scale land and water resource development. This contributed to expansion of the irrigated area and increased the precision of water treatment.

The economic incentives for expansion of rice area and the adoption of yield-improving technology were favorable throughout the first epoch. Real rice prices rose, throughout the period, Tables III.4 and III.5. By 1900 rice exports, which had risen continuously since the early 1870's started to decline. Demand was increasing more rapidly than supply. The government's response was to undertake an intensive program to expand rice production in the northern island of Hokkaido and in newly-acquired colonial areas of Korea and Taiwan.

Output and Productivity Growth in Korea and Taiwan

Initial efforts to increase rice production in Korea and Taiwan through the transfer of Japanese rice varieties and Japanese cultivation methods were relatively unsuccessful.[28/]

In Korea, where the environment for rice cultivation was similar to that in Japan, the transfer of Japanese varieties occurred rather rapidly. By the early 1920's approximately two-thirds of the rice area in Korea was planted to Japanese varieties, Table III.6. However, rice yields in Korea did not increase significantly until at least the mid-1920's (Table III.7).

In Taiwan the direct transfer of Japanese varieties was not successful. Japanese rice varieties were not adapted to the Taiwan ecology. Furthermore, the official economic policy emphasized expansion of sugar production rather than rice production during the first two decades of the colonial period. It was not until the mid-1920's, after 30 years of Japanese rule, that new varieties were developed. These varieties incorporated the high yield potential of the Japanese varieties with the superior adaptation to local conditions of the native _indica_ varieties.[29/] By the late 1930's half of the total rice area in Taiwan was planted to the new _ponlai_ varieties developed in Taiwan. The average Taiwan rice yield was approaching that in Japan. This rapid diffusion was facilitated by extensive irrigation development.

By the mid-1920's, the increases in rice output in the colonial areas resulted in substantially increased rice exports to Japan, Table III.3. Japanese rice imports rose from an average of 559 metric tons in 1912-20, 6.4 percent of total Japanese supply, to 1,754 metric tons in 1931-40, 15.6 percent of total supply. During this latter period, imports from Korea accounted for 9.6 percent and from Taiwan 5.5 percent of the total Japanese rice supply.

In Taiwan, rice exports rose from an average of less than 20 percent of total production during the 1911-20 period to 31 percent in 1921-30 and 47 percent in 1931-40, Table III.10. In Korea, exports rose from less than 9 percent in 1912-16 to 30 percent in 1922-26, Table III.11.

The extent to which the increased rice exports from the two colonial areas were a result of economic incentives generated in the market or administrative pressures has not yet been analyzed. Although data on consumption levels in the two colonial areas are subject to considerable question it does seem clear that consumption of rice in Korea and Taiwan declined while exports to Japan were rising. In Taiwan, the per capita supply of rice available for local use declined from 166.5 kilograms per capita in 1920-29 to 133.1 kilograms in 1930-39. In Korea, per capita consumption of rice also appears to have declined sharply while exports to Japan were rising. In contrast, rice consumption in Japan during the 1930's approximated the levels of earlier years, Table III.12.

Impact of Rice Imports on Japanese Prices, Production, and Productivity

The two decades from 1920 to 1940 have been characterized as a period of relative stagnation in Japanese agriculture. For 30 years prior to World War I, rice prices had risen steadily relative to the general price level. Rice prices rose to their highest relative level in 1913 and their highest absolute level in 1919, Table III.4 and III.5. The wholesale price of rice in Tokyo more than doubled between 1913 and 1919. Consumer riots occurred during the very sharp price rise of 1916-19. In response to these official policies were designed to encourage rice production in and imports from the colonial areas.

Imports increased sharply in the mid-1920's and remained above 1.2 million metric tons until after 1940, Table III.12. From 1921-40, the price of rice did not resume its upward drift relative to the general price level. It fluctuated below the peak established in 1913. The sharp decline in rice prices in the early 1930's led to protests by farmers against imports. The government limited imports from the two colonial areas in 1933 and again in 1936. Nevertheless, rice imports averaged 1.9 million metric tons in 1932-38, and reached their pre-World War II peak of 2.2 million metric tons in 1938.

What was the impact of rice imports from Taiwan and Korea on rice production, consumption, and prices in Japan during the interwar period? The impact of imports depends upon the shape of the rice demand and supply functions in Japan during this period.

Estimates of the price elasticity of demand computed by Ohkawa from (1) data on rice consumption by income classes between 1931-32 and 1938-39 and (2) from market data between 1920 and 1938 center around -0.20. /32/ Recent income elasticity estimates, summarized by Kaneda also appear consistent with a price elasticity for rice of -0.20 in the 1920-40 period. /22/

Estimates of supply elasticities in rice production are unavailable for Japan. The elasticity of supply depends on both the response of area planted and the response of yield per unit area to changes in the price of rice. Recent review of area supply elasticity studies conducted in other Asian countries, indicate that the area response to changes in the price of rice typically falls in the +0.20 to +0.30 range. /23, 24/ The yield of rice per unit area in Japan was apparently highly responsive to the use of fertilizer, insecticides, and other technical inputs during this period. Estimates of the production function and the demand for fertilizer by Hayami imply an elasticity of yield with respect to price of between +0.20 and +0.25. [13, 14] It seems reasonable, therefore, to hypothesize a total supply elasticity for rice of approximately +0.50 in Japan between 1920-40.

With these two elasticity estimates it is possible to arrive at an estimate of the impact of rice imports on Japanese rice production, consumption, and price by constructing three, simple economic models for the 1921-40 period, Table III.13.

The first model, identified in Table III.13 as "partial isolation model (I)", illustrates the impact of imports on rice prices when (1) annual domestic production is the same as actually occurred in the 1921-40 period -- this implies a completely inelastic supply function, (2) imports are held at the 1912-20 average level, and (3) the price elasticity of demand is assumed to be -0.2. Under these conditions rice prices would have risen to an average index of 140 for the 1931-40 period, 43 percent higher than the actual average index of 97 that prevailed during 1931-40.

The second model, identified as "partial isolation model (II)", illustrates the impact on rice prices when (1) the price elasticity of supply is assumed to be +0.5, (2) imports are held at the 1912-20 average level, and (3) the price elasticity of demand is assumed to be -0.2. It differs from partial isolation model (I) only in the assumption with respect to supply elasticity. Under these conditions, rice prices would have risen to an average index of 107 for the 1931-40 period, 11 percent higher than the actual average index for the same period.

The third model, called the "isolation model", illustrates the estimated impact of imports on rice prices, production, and consumption when (1) imports are assumed to have been prohibited in the 1921-40 period, (2) the price elasticity of demand is assumed to be -0.2, and (3) the price elasticity of supply is assumed to be +0.5. Under these conditions the average 1931-40 price index would be 115. This is 19 percent above the actual 1931-40 index of 97.

The prices generated by the "isolation model" are consistent with an estimated rate of growth in rice production in Japan equal to that achieved during the first two decades of this century.[30/] The "isolation model" is therefore, consistent with the hypothesis referred to at the beginning of this section; that imports of rice from Taiwan and Korea were responsible for the depressed rice prices and the slow growth of rice production in metropolitan Japan during the 1920-40 period.[31/] However, the data and analysis presented in this paper is inadequate to reject the hypothesis that technical considerations also could have dampened the rate of growth of output even if the calculated equilibrium prices had been obtained.

The impact of the rice imports from Taiwan and Korea on Japanese economic growth is less obvious than their impact on rice production and prices. Clearly one major impact of these rice imports was to reverse the long-run tendency for terms of trade to shift in favor of rice producers and turn it in favor of rice consumers. This contributed to higher real incomes for urban consumers, increased the supply of labor in the nonfarm sector, and reduced pressures for wage increases in the industrial sector. One effect was probably to increase the competitive position of Japanese industrial exports in world markets. A second effect was to reduce the growth rate of purchasing power in rural areas. This, in turn contributed to the slack in domestic private demand for the industrial sector's output. /10; pp. 419-442/

The transfer of rice production technology from Japan to Taiwan and Korea and the Japanese policy on imports from these two countries during 1920-40 period has important implications for South and Southeast Asian countries for the rest of this century. Approximately two-thirds of the world rice trade today is between Asian countries. /2/ Technical change in rice production, similar to the changes that took place in Taiwan and Korea prior to World War II, is underway in several rice exporting and importing nations of Southeast Asia. Substantial disruption of trade and price relationships are anticipated in the absence of an effective international stabilization scheme.

Table III.1.--Annual percentage growth rates of output, inputs and productivity in Japanese agriculture in four periods

	Phase I (1882-1917)	Phase II (1917-1937)	Phase III (1937-1947)	Phase IV (1947-1957)
		- percent per year -		
Output:				
Gross output	1.78	.80	-2.79	4.51
Net output	1.37	.69	-1.78	2.14
Conventional inputs:				
Total inputs	.28	.28	- .03	1.41
Labor	.20	.01	1.83	-1.36
Fixed capital				
Including building	.43	.52	- .46	1.70
Excluding building	1.66	1.24	-1.44	3.62
Variable inputs	2.93	1.15	-6.76	12.02
Land acreage total	.60	.15	- .54	.35
Paddy field	.27	.34	- .43	.31
Upland field	1.02	.05	- .67	.39
Productivity per unit of:				
Conventional inputs	1.49	.49	-2.77	3.05
Labor	1.86	.81	-4.54	5.84
Fixed capital				
Including building	1.34	.27	-2.35	2.76
Excluding building	.11	- .44	-1.37	.85
Variable inputs	-1.12	- .45	4.25	-6.71
Land	1.17	.64	-2.27	4.14

/47; pp. 371-413/

Table III.2.--Five-year averages of official and corrected paddy rice yields in Japan, 1873-1922

Period	Official estimates[a]	Yamada-Hayami estimates[b]	Nakamura estimates[c] (1)	(2)	(3)
	yields in koku per tan of brown rice[d]				
1873-1877	----	----	1.500	1.600	1.700
1878-1882	1.166	1.264	1.549	1.636	1.721
1883-1887	1.297	1.355	1.599	1.672	1.743
1888-1892	1.428	1.425	1.651	1.709	1.764
1893-1897	1.371	1.371	1.705	1.747	1.786
1898-1902	1.516	1.516	1.760	1.786	1.808
1903-1907	1.626	1.626	1.817	1.826	1.831
1908-1912	1.734	1.734	1.876	1.867	1.854
1913-1917	1.843	1.843	1.937	1.908	1.877
1918-1922	1.927	1.927	2.000	1.950	1.900
	- percent -				
annual average growth rate	1.3	1.1	0.6	0.4	0.2

[a]Ministry of Agriculture and Forestry, Agricultural Forestry Economics Bureau, Statistical Section, Reported by Nakamura (27; pp. 66, 228-230).

[b]Kazushi Ohkawa, et. al. Estimates of Long Term Economic Statistics of Japan Since 1868, Vol. 9, Tokyo, 1963, p. 67.

[c] (27; p. 92).

[d]One koku equals 150 kilograms; one tan equals 0.0992 hectares.

Table III.3.--Production, area, and yield of brown rice in Japan, 1900-1940

Year	Production[a/]			Area planted[b/]			Yield		
	Total	Paddy	Upland	Total	Paddy	Upland	Total	Paddy	Upland
	- thousand metric tons -			- thousand hectares -			- kilograms per hectare -		
1900-1901	6,220	6,122	98	2,805	2,731	74	2,217	2,242	1,325
1901-1902	7,037	6,929	108	2,824	2,745	79	2,492	2,525	1,366
1902-1903	5,540	5,449	91	2,824	2,740	83	1,962	1,989	1,090
1903-1904	6,971	6,872	99	2,840	2,755	85	2,454	2,494	1,162
1904-1905	7,713	7,627	86	2,857	2,774	82	2,700	2,749	1,046
1905-1906	5,726	5,637	89	2,858	2,783	74	2,004	2,025	1,195
1906-1907	6,945	6,842	103	2,875	2,799	77	2,416	2,444	1,363
1907-1908	7,358	7,238	120	2,882	2,804	78	2,553	2,581	1,53[illegible]
1908-1909	7,790	7,658	132	2,898	2,815	83	2,688	2,720	1,594
1909-1910	7,866	7,732	134	2,914	2,827	86	2,699	2,735	1,545
1910-1911	6,996	6,855	140	2,925	2,834	91	2,392	2,419	1,526
1911-1912	7,757	7,602	154	2,949	2,852	97	2,630	2,665	1,599
1912-1913	7,533	7,389	144	2,978	2,869	109	2,530	2,575	1,322
1913-1914	7,539	7,374	165	3,005	2,886	118	2,509	2,555	1,392
1914-1915	8,551	8,381	170	3,008	2,886	122	2,842	2,904	1,383
1915-1916	8,389	8,189	200	3,031	2,907	124	2,767	2,817	1,607
1916-1917	8,768	8,534	234	3,046	2,918	128	2,879	2,924	1,831
1917-1918	8,185	8,015	170	3,058	2,928	130	2,677	2,738	1,309
1918-1919	8,205	8,022	184	3,067	2,935	132	2,675	2,733	1,392
1919-1920	9,123	8,887	236	3,079	2,943	136	2,963	3,019	1,741
1920-1921	9,481	9,205	276	3,101	2,960	140	3,058	3,105	1,969
1921-1922	8,277	8,055	222	3,109	2,968	141	2,662	2,714	1,572
1922-1923	9,104	8,907	203	3,115	2,972	143	2,923	2,995	1,420
1923-1924	8,317	8,120	197	3,121	2,982	139	2,664	2,723	1,411
1924-1925	8,576	8,425	150	3,117	2,980	137	2,752	2,827	1,101
1925-1926	8,956	8,716	239	3,128	2,993	135	2,863	2,913	1,768
1926-1927	8,339	8,150	189	3,132	2,996	136	2,662	2,720	1,385
1927-1928	9,315	9,083	232	3,147	3,013	134	2,960	3,014	1,731
1928-1929	9,045	8,812	233	3,165	3,030	136	2,858	2,909	1,719
1929-1930	8,934	8,802	132	3,184	3,050	134	2,806	2,886	979

(continued)

Table III.3.--(continued)

Year	Production[a]			Area planted[b]			Yield		
	Total	Paddy	Upland	Total	Paddy	Upland	Total	Paddy	Upland
	- thousand metric tons -			- thousand hectares -			- kilograms per hectare -		
1930-1931	10,031	9,790	242	3,212	3,079	133	3,123	3,179	1,812
1931-1932	8,282	8,098	184	3,222	3,089	133	2,571	2,622	1,384
1932-1933	9,058	8,852	206	3,230	3,097	133	2,804	2,858	1,549
1933-1934	10,624	10,439	185	3,147	3,022	124	3,376	3,454	1,484
1934-1935	7,776	7,634	142	3,147	3,022	124	2,471	2,526	1,138
1935-1936	8,618	8,414	205	3,178	3,044	134	2,712	2,764	1,528
1936-1937	10,101	9,836	265	3,180	3,042	139	3,176	3,234	1,909
1937-1938	9,948	9,766	182	3,190	3,044	146	3,130	3,208	1,246
1938-1939	9,880	9,628	252	3,194	3,048	146	3,093	3,159	1,722
1939-1940	10,345	10,052	292	3,166	3,016	150	3,267	3,333	1,942
Average									
1900-1901 to 1909-1910	6,916	6,811	106	2,858	2,777	80	2,419	2,450	1,322
1910-1911 to 1919-1920	8,104	7,925	180	3,015	2,896	119	2,688	2,686	1,510
1920-1921 to 1929-1930	8,839	8,627	207	3,132	2,994	138	2,821	2,881	1,505
1930-1931 to 1939-1940	9,466	9,251	216	3,186	3,187	136	2,972	3,034	1,571

a/Converted from koku to metric tons at 150 kg. per koku.
b/Converted from cho to hectares at .991736 ha per cho.
Source: Japan Statistical Yearbook, Bureau of Statistics. Office of the Prime Minister, 1949, p. 203, 1961, p. 90, 1964, p. 98.

Table III.5.--Price indexes for rice and wholesale price index in Japan, 1911-1940 (1934-36 = 100)

Year	Wholesale price index (G)	Rice price Index $(R)_1$	Rice price Ratio $(R/G)_1$	Rice price Index $(R)_2$	Rice price Ratio $(R/G)_2$
1911	61.0	60.2	.99	60.5	.99
1912	64.6	72.0	1.11	72.2	1.12
1913	64.7	74.9	1.16	74.8	1.16
1914	61.8	56.1	.91	56.4	.91
1915	62.5	45.4	.73	45.6	.73
1916	75.6	47.5	.63	47.7	.63
1917	95.1	68.3	.72	69.1	.73
1918	124.6	113.0	.91	113.4	.91
1919	152.6	159.6	1.05	160.1	1.05
1920	167.8	153.9	.92	154.5	.92
1921	129.6	107.2	.83	107.8	.83
1922	126.7	121.6	.96	122.6	.97
1923	128.9	113.4	.88	113.0	.88
1924	133.6	133.8	1.00	133.7	1.00
1925	130.5	144.5	1.11	145.0	1.11
1926	115.7	130.6	1.13	131.1	1.13
1927	109.9	122.0	1.11	122.9	1.12
1928	110.6	107.2	.97	107.1	.97
1929	107.5	100.7	.94	100.9	.94
1930	88.5	88.0	.99	64.1	.72
1931	74.8	63.8	.85	64.1	.86
1932	83.0	73.3	.88	73.6	.89
1933	95.1	74.5	.78	74.5	.78
1934	97.0	90.5	.93	90.5	.93
1935	99.4	103.1	1.04	103.2	1.04
1936	103.6	106.4	1.03	106.2	1.03
1937	125.8	-----	----	112.2	.89
1938	132.7	-----	----	119.2	.90
1939	146.6	-----	----	129.6	.88
1940	164.1	-----	----	150.7	.92
Average					
1911-20	93.0	85.1	.91	85.4	.92
1921-30	118.2	116.9	.99	114.8	.97
1931-40	112.2	-----	----	102.4	.91

Source: Wholesale Price Index: Hundred Year Statistics of the Japanese Economy, Statistics Department, Bank of Japan, 1966. pp. 76, 77.

Rice Price Index (1): Japan Statistical Yearbook, 1949, p. 634, The index base has been shifted from 1900=100 to 1934-36=100.

Rice Price Index (2): Hundred Year Statistics of the Japanese Economy, Statistics Department, Bank of Japan, 1966, p. 90.

Table III.6.--Plantings of Japanese type and Ponlai rice varieties in Korea and Taiwan, selected years

Year	Plantings of Japanese-type varieties: Area	Plantings of Japanese-type varieties: Percent of total rice area	Average yield of brown rice
	thousand hectares	percent	kilograms/ hectare
KOREA			
1912	39	3	1,160
1917	590	41	1,354
1922	979	67	1,458
1927	1,163	77	1,633
1932	1,245	80	1,504

	Plantings of Ponlai varieties: Area	Plantings of Ponlai varieties: Percent of total rice area	Average yield of brown rice (Paddy)
	thousand hectares	percent	kilograms/ hectare
TAIWAN			
1922			
1st crop[a]	.4	.2	1,749
2nd crop			1,420
1926			
1st crop	111.8	45.2	1,644
2nd crop	11.4	3.9	1,573
1930			
1st crop	80.4	30.6	1,883
2nd crop	54.9	16.6	1,624
1935			
1st crop	186.9	64.8	2,243
2nd crop	118.0	32.0	2,057

a/The 1st crop in Taiwan is the dry season crop.

Source: /31; p. 190/
Japan Statistical Year Book, Bureau of Statistics, Office of the Prime Minister, 1949, pp. 630, 631.
Taiwan Food Statistics, Taiwan Provincial Food Bureau, 1965, (and earlier issues), Taipei, pp. 18-22.

Table III.7.--Production, area and yield of brown rice in Korea, 1912-1940

Year	Production	Area	Yield
	thousand metric tons	hectares	kilograms/ hectare
1912-1913	1,630	1,405	1,160
1913-1914	1,816	1,445	1,257
1914-1915	2,120	1,472	1,440
1915-1916	1,927	1,485	1,297
1916-1917	2,090	1,506	1,387
1917-1918	2,053	1,516	1,354
1918-1919	2,294	1,535	1,494
1919-1920	1,906	1,525	1,250
1920-1921	2,232	1,543	1,447
1921-1922	2,149	1,519	1,415
1922-1923	2,252	1,545	1,458
1923-1924	2,276	1,538	1,480
1924-1925	1,983	1,563	1,269
1925-1926	2,215	1,572	1,410
1926-1927	2,295	1,575	1,457
1927-1928	2,595	1,589	1,633
1928-1929	2,027	1,505	1,346
1929-1930	2,055	1,619	1,270
1930-1931	2,877	1,648	1,746
1931-1932	2,381	1,661	1,434
1932-1933	2,452	1,630	1,504
1933-1934	2,729	1,783	1,531
1934-1935	2,508	1,698	1,477
1935-1936	2,683	1,681	1,596
1936-1937	2,912	1,588	1,833
1937-1938	4,020	1,626	2,473
1938-1939	3,621	1,646	2,200
1939-1940	2,153	1,225	1,758
Average			
1912-1913 to 1919-1920	1,980	1,486	1,330
1920-1921 to 1929-1930	2,208	1,557	1,418
1930-1931 to 1939-1940	2,833	1,618	1,755

Source: Japan Statistical Year Book, Bureau of Statistics, Office of the Prime Minister, 1949, pp. 630, 631.

Table III.8.--Production,area and yield of brown rice in Taiwan, 1900-1940

Year	Production	Area	Yield
	thousand metric tons	hectares	kilograms/ hectare
1900-1901	307	326	943
1901-1902	438	353	1,239
1902-1903	403	345	1,168
1903-1904	525	395	1,330
1904-1905	594	435	1,366
1905-1906	622	447	1,390
1906-1907	567	459	1,236
1907-1908	645	472	1,367
1908-1909	665	479	1,389
1909-1910	661	479	1,381
1910-1911	598	456	1,311
1911-1912	642	479	1,340
1912-1913	578	481	1,201
1913-1914	732	498	1,482
1914-1915	658	500	1,317
1915-1916	684	491	1,392
1916-1917	664	472	1,408
1917-1918	691	466	1,481
1918-1919	662	483	1,369
1919-1920	703	497	1,415
1920-1921	692	500	1,383
1921-1922	711	495	1,435
1922-1923	778	511	1,521
1923-1924	695	508	1,369
1924-1925	668	531	1,633
1925-1926	920	551	1,671
1926-1927	888	567	1,565
1927-1928	985	585	1,685
1928-1929	971	585	1,660
1929-1930	926	568	1,630
1930-1931	1,053	614	1,714
1931-1932	1,069	634	1,686
1932-1933	1,278	664	1,924
1933-1934	1,195	675	1,768
1934-1935	1,298	667	1,947
1935-1936	1,303	679	1,920
1936-1937	1,366	681	2,004
1937-1938	1,319	658	2,006
1938-1939	1,402	625	2,242
1939-1940	1,307	626	2,088

(continued)

Table III.8.--(continued)

Year	Production	Area	Yield
	thousand metric tons	hectares	kilograms/ hectare
Average			
1900-1910 to 1909-1910	543	419	1,281
1910-1911 to 1919-1920	661	482	1,372
1920-1921 to 1929-1930	823	540	1,555
1930-1931 to 1939-1940	1,259	652	1,930

Source: Taiwan Food Statistics, 1964, Taiwan Provincial Food Bureau, Taipei, 1964, pp. 2-3.

Table III.9.--Japanese rice production and imports from Korea and Taiwan, actual amounts and percent of total Japanese supply, 1912-1961

	Production		Net imports						Supply[a]
			Total		Korea		Taiwan		
Year	Thous. metric tons	Percent of supply	Thous. metric tons	Percent of supply	Thous. metric tons	Percent of supply	Thous. metric tons	Percent of supply	Thous. metric tons
1912	7,757	95.2	392	4.8	36	.4	91	1.1	8,148
1913	7,533	92.1	642	7.9	44	.5	141	1.7	8,175
1914	7,539	92.8	588	7.2	153	1.9	115	1.4	8,127
1915	8,551	96.1	345	3.9	280	3.2	95	1.1	8,897
1916	8,389	97.3	231	2.7	198	2.3	109	1.3	8,620
1917	8,768	98.6	120	1.4	177	2.0	105	1.2	8,888
1918	8,185	90.0	909	10.0	258	2.8	159	1.7	9,094
1919	8,205	85.6	1,377	14.4	418	4.4	185	1.9	9,582
1920	9,123	95.5	427	4.5	246	2.6	96	1.0	9,550
1921	9,481	93.4	671	6.6	431	4.2	149	1.5	10,152
1922	8,277	89.0	1,024	11.0	447	4.8	72	.8	9,301
1923	9,104	91.7	825	8.3	505	5.1	161	1.6	9,929
1924	8,317	86.4	1,313	13.6	609	6.3	233	2.4	9,640
1925	8,576	84.9	1,525	15.1	552	5.5	281	2.9	10,100
1926	8,956	86.9	1,348	13.1	762	7.4	324	3.1	10,303
1927	8,339	83.0	1,706	17.0	774	7.7	393	3.9	10,045
1928	9,316	85.8	1,537	14.2	1,049	9.7	361	3.3	10,853
1929	9,046	87.8	1,253	12.2	788	7.7	336	3.3	10,298
1930	8,934	88.1	1,207	11.9	763	7.5	327	3.2	10,140
1931	10,031	87.5	1,429	12.5	1,194	10.4	404	3.5	11,460
1932	8,282	83.5	1,639	16.5	1,073	10.8	516	5.2	9,921
1933	9,059	83.3	1,819	16.7	1,123	10.3	632	5.8	10,877
1934	10,624	84.2	1,997	15.8	1,338	10.6	768	6.1	12,621
1935	7,776	80.9	1,833	19.1	1,249	13.0	676	7.0	9,609

(continued)

Table III.9.--(continued)

Year	Production		Net imports: Total		Net imports: Korea		Net imports: Taiwan		Supply[a]
	Thous. metric tons	Percent of supply	Thous. metric tons	Percent of supply	Thous. metric tons	Percent of supply	Thous. metric tons	Percent of supply	Thous. metric tons
1936	8,618	80.8	2,047	19.2	1,343	12.6	723	6.8	10,666
1937	10,101	85.7	1,685	14.3	1,006	8.5	728	6.2	11,786
1938	9,948	81.9	2,203	18.1	1,519	12.5	744	6.1	12,151
1939	9,880	87.9	1,357	12.1	838	7.5	593	5.3	11,237
1940	10,345	87.1	1,533	12.9	49	.4	417	3.5	11,878
Average									
1912-1920	8,228	93.6	559	6.4	201	2.3	122	1.4	8,787
1921-1930	8,834	87.7	1,241	12.3	668	6.6	264	2.6	10,075
1931-1940	9,467	84.4	1,754	15.6	1,073	9.6	620	5.5	11,221

a/Supply equals production plus net imports.

Source: Japan Statistical Year Book, Bureau of Statistics, Office of the Prime Minister, 1949, pp. 614-615. Data converted from koku to metric tons at 150 kg. per koku.

Table III.10.--Rice supplies, trade, and domestic utilization in Taiwan, 1910-1911 to 1939-1940

Year[a/]	Supply			Domestic utilization	Exports	Exports as percent of production
	Production	Imports	Total			
	- thousand metric tons -					- percent -
1910-1911	641	13	654	560	94	15
1911-1912	578	18	596	503	93	16
1912-1913	732	30	762	601	161	22
1913-1914	658	11	669	583	86	13
1914-1915	684	9	693	567	126	18
1915-1916	664	11	675	564	111	17
1916-1917	691	17	708	591	117	17
1917-1918	662	48	710	559	156	23
1918-1919	703	57	760	591	169	24
1919-1920	692	27	719	615	104	15
1920-1921	711	21	732	586	146	21
1921-1922	778	47	825	718	107	14
1922-1923	695	15	710	531	179	26
1923-1924	868	18	886	624	262	30
1924-1925	920	117	1,037	682	355	39
1925-1926	888	67	955	643	312	35
1926-1927	985	129	1,115	742	373	38
1927-1928	971	46	1,017	678	339	35
1928-1929	926	92	1,018	687	331	36
1929-1930	1,053	14	1,067	750	317	30
1930-1931	1,069	2	1,071	691	380	36
1931-1932	1,278	37	1,315	838	477	37
1932-1933	1,195	8	1,203	613	590	49
1933-1934	1,298	1	1,299	578	721	56
1934-1935	1,303	1	1,304	662	642	49

(continued)

Table III.10.--(continued)

Year[a/]	Supply: Production	Supply: Imports	Supply: Total	Domestic utilization	Exports	Exports as percent of production
	- thousand metric tons -					- percent -
1935-1936	1,365	1	1,366	683	683	50
1936-1937	1,319	1	1,320	628	692	52
1937-1938	1,402	2	1,404	708	696	50
1938-1939	1,307	1	1,308	722	586	45
1939-1940	1,129	13	1,142	719	423	37
Average						
1910-1911 to 1919-1920	671	24	695	573	122	18
1920-1921 to 1929-1930	880	57	937	664	273	31
1930-1931 to 1939-1940	1,267	7	1,274	684	590	47

a/The rice year in Taiwan is November 1 to October 31 for years prior to 1945. This was changed to July 1 to June 30 in 1945.

Source: Taiwan Provincial Food Bureau, Taiwan Food Statistics, 1965 (and earlier issues), Taipei.

Table III.11.--Korean rice production and exports to Japan, annual averages 1912-1916, 1917-1921, 1922-1926

Years (average)	Production	Exports	Exports as percent of production
	- thousand metric tons -		- percent -
1912-1916	1,771	152	8.5
1917-1921	2,030	316	15.6
1922-1926	2,088	625	29.9

Source: [48; p. 315].

Table III.12.--Per capita annual consumption of rice in Japan, Taiwan and Korea, 1910-1940

Year	Japan	Taiwan	Korea (old series)	Korea (new series)
		- kilograms per person -		
1910	162.6	-----	-----	
1911	147.0	-----	-----	
1912	160.2	-----	115.9	
1913	158.6	-----	104.8	
1914	147.2	-----		106.8
1915	166.7	-----	110.6	
1916	161.6	-----	101.0	
1917	168.9	-----	108.0	
1918	171.5	-----	102.0	
1919	168.6	-----		108.7
1920	167.7	192.4	95.1	
1921	173.0	154.2	100.6	
1922	165.0	185.5	95.1	
1923	173.0	134.9	97.1	
1924	168.3	155.6		90.5
1925	169.2	166.7	77.8	
1926	169.5	153.1	79.9	
1927	164.3	173.0	78.7	
1928	169.4	154.5	81.0	
1929	165.0	195.3	66.9	
1930	161.4	162.5	67.6	
1931	167.7	145.7	78.0	
1932	151.8	172.2	61.8	
1933	162.5	122.8	61.5	
1934	170.0	112.7	62.5	
1935	154.1	126.0	58.2	
1936	157.1	126.8	58.2	85.2
1937	166.7	113.6	-----	105.5
1938	166.8	124.6	-----	116.4
1939	165.5	124.0	-----	-----
Average				
1910-1919	161.3	-----	107.2[a]	
1920-1929	168.4	166.5	86.3	
1930-1939	162.4	133.1	64.0[b]	102.4[c]

a/1912-1919
b/1930-1936
c/1936-1938
Source: Japan: Hundred Year Statistics of the Japanese Economy, Statistics Department, Bank of Japan, Tokyo, 1966.
(continued)

Table III.12.--(continued)

Source: (continued)

Taiwan: Taiwan Food Statistics, 1965 (and earlier issues), Taiwan Provincial Food Bureau, Taipei. The Taiwan data represents per capita supply available for domestic utilization rather than per capita consumption.

Korea: Chosen Beikoku Yoran (Rice Situation in Korea), Department of Agriculture and Forestry, Korean Governor's office, Seoul, 1936 and 1940.

Table III.13.--Actual and estimated prices of rice in Japan with demand model and isolation model, 1921-1940 (Partial Isolation Model I)

Year	Actual data				Partial Isolation Model (I)				Isolation Model	
	Production	Imports	Supply	Price index[a/]	Production	Imports	Supply	Price index	Production[b/]	Price index
	- thous. metric tons -			-percent-	-thous. metric tons -			-percent-	-thous.metric tons -	-percent-
1921	9,481	671	10,152	83	9,481	559	10,040	88	9,951	91
1922	8,277	1,024	9,301	97	8,277	559	8,835	121	8,983	114
1923	9,104	825	9,929	88	9,104	559	9,663	100	9,679	99
1924	8,317	1,313	9,630	100	8,317	559	8,876	139	9,214	122
1925	8,575	1,525	10,100	111	8,575	559	9,134	164	9,612	138
1926	8,955	1,348	10,303	113	8,956	559	9,515	156	9,879	136
1927	8,339	1,706	10,045	112	8,339	559	8,898	176	9,490	143
1928	9,316	1,537	10,853	97	9,316	559	9,874	140	10,364	119
1929	9,045	1,253	10,298	94	9,045	559	9,604	125	9,906	112
1930	8,933	1,207	10,140	72	8,934	559	9,493	95	9,764	85
1931	10,031	1,429	11,460	86	10,031	559	10,590	118	11,012	103
1932	8,282	1,639	9,921	89	8,282	559	8,841	137	9,390	113
1933	9,058	1,819	10,877	78	9,058	559	9,617	123	10,287	99
1934	10,625	1,997	12,622	93	10,625	559	11,183	146	11,978	117
1935	7,776	1,833	9,609	104	7,776	559	8,335	173	9,002	137
1936	8,619	2,047	10,666	103	8,619	559	9,177	175	9,988	136
1937	10,101	1,685	11,786	89	10,101	559	10,660	131	11,250	109
1938	9,948	2,203	12,151	90	9,948	559	10,507	150	11,428	117
1939	9,880	1,357	11,237	88	9,880	559	10,439	119	10,813	105
1940	10,345	1,533	11,878	92	10,345	559	10,904	129	11,395	111
Average										
1921-1930	8,834	1,241	10,075	92	8,834	559	9,393	130	9,684	116
1931-1940	9,467	1,754	11,221	97	9,466	559	10,025	140	10,654	115

(continued)

Table III.13.--(continued) (Partial Isolation Model (II))

Year	Actual data				Partial Isolation Model (II)				Isolation Model	
	Production	Imports	Supply	Price index a/	Production	Imports	Supply	Price index	Production b/	Price index
	-thous. metric tons -			-percent-	-thous. metric tons -			-percent-	-thous. metric tons-	-percent-
1921	9,481	671	10,152	83	9,559	559	10,118	84	9,951	91
1922	8,277	1,024	9,301	97	8,598	559	9,157	105	8,983	114
1923	9,104	825	9,929	88	9,289	559	9,848	92	9,679	99
1924	8,317	1,313	9,630	100	8,832	559	9,391	112	9,214	122
1925	8,575	1,525	10,100	111	9,250	559	9,809	129	9,612	138
1926	8,955	1,348	10,303	113	9,495	559	10,054	127	9,879	136
1927	8,339	1,706	10,045	112	9,113	559	9,672	133	9,490	143
1928	9,316	1,537	10,853	97	9,983	559	10,542	111	10,364	119
1929	9,045	1,253	10,298	94	9,522	559	10,081	104	9,906	112
1930	8,933	1,207	10,140	72	9,379	559	9,938	79	9,764	85
1931	10,031	1,429	11,460	86	10,628	559	11,187	96	11,012	103
1932	8,282	1,639	9,921	89	9,012	559	9,571	105	9,390	113
1933	9,058	1,819	10,877	78	9,909	559	10,468	93	10,287	99
1934	10,625	1,997	12,622	93	11,600	559	12,159	110	11,978	117
1935	7,776	1,833	9,609	104	8,629	559	9,188	127	9,002	137
1936	8,619	2,047	10,666	103	9,614	559	10,173	127	9,988	136
1937	10,101	1,685	11,786	89	10,869	559	11,428	103	11,250	109
1938	9,948	2,203	12,151	90	11,052	559	11,611	110	11,428	117
1939	9,880	1,357	11,237	88	10,429	559	10,988	98	10,813	105
1940	10,345	1,533	11,878	92	11,013	559	11,572	104	11,395	111
Average										
1921-1930	8,834	1,241	10,075	92	9,302	559	9,358	108	9,684	116
1931-1940	9,467	1,754	11,221	97	10,276	559	10,332	107	10,654	115

a/1934-1936 = 100.

b/equals supply.

Source: See table III.5 and III.9 for source of actual data.

IV. SUMMARY

We recognize that it is difficult to draw broad inferences about future patterns of international generation and transmission of technology in agricultural products from the evidence in these three cases. However, we will summarize the common elements that we see in these three cases. We will also draw on this and other related work in making some tentative inferences regarding future patterns of international technical change in agricultural products.

Technical change in all three cases was generated by organized research effort, the effort being more highly organized the more advanced the basic technology. Early sugarcane breeding, for example, was sometimes accomplished on individual plantations. Virtually all of the major canes, however, were the product of experiment station research. The Stage IV varieties were all produced by scientists using advanced techniques and working in well-organized research establishments. Likewise, advances in rice breeding were and are being produced by experiment stations established for this purpose. The advances in banana production were generated by researchers working with large private organizations.[32/]

Research accomplishments have in many cases followed concentrated effort to solve specific economic problems. The accomplishments in the banana case can be traced to the effort put forth in response to the problems caused by Panama disease. Later, the problems associated with handling and processing the new disease-resistant varieties led to immany instances in which a disease problem formed the basis for a sustained effort to find new disease-resistant, higher-yielding varieties.

The international transmission of technical change is a function of both the specific characteristics of the technology and of economic incentives. The characteristics of the technology that appear to be most important concern the information or knowledge required to implement the technology into actual production processes. The simplest form of technology from this point of view might be a new higher-yielding crop variety which is adapted to a wide range of climate and soil conditions and does not require any changes in producing, processing, or marketing techniques. Some of the early transfer of sugarcane varieties was of this sort. Only the economic incentive of profitability was needed to encourage rapid international transmission of these varieties.

Information is needed for international transmission even when the technology is embodied simply in the seed of a plant variety. A grower must have some information about the relative yield and quality of a new variety before he can determine whether a change is profitable. This information was relatively easy to obtain for those sugarcane varieties which were adapted to wide climatic and soil conditions. The Stage II sugarcane varieties were thus transferred relatively easily.

The transmission of technology becomes more difficult as more information is required. For example, the Stage III sugarcane varieties were not easily transferred. Specific information was needed regarding each of the new varieties were resistant. A similar degree of information was required in the banana disease case. Rapid transmission of technology requiring this degree of information took place only with the organized testing effort of experiment stations or of large private concerns.

Transmission is further complicated when knowledge is required regarding new production, processing, and marketing techniques. In the banana case, the solution to the processing and marketing problems took the form of important new technical advance. The transmission of rice varieties from Japan to Korea also involved knowledge of new cultural practices. In addition to organized research effort, some form of extension effort often is required to achieve transmission of new technology.

The most complicated and sophisticated forms of technical transfer are those illustrated by the Stage IV sugarcane breeding effort and the transfer of rice technology from Japan to Taiwan. In these cases, the technology that was transferred was not directly embodied in a tangible input such as a plant seed. It took the form of knowledge or scientific information regarding plant breeding techniques.

Technology transfer of this kind depends heavily on the existence of effective research organizations. A minimum number of competent research scientists committed to the transfer and further development of this technology are required. In addition, the organization must provide the environment for the communication and complementary inter-

One would expect to find the lag or "technology gap" that exists between the most advanced technology used in the production of a given crop and the least advanced technology to be related to the difficulty of international transmission. Thus, in cases in which the technology is embodied in an input and where little information is needed to determine the profitability of that input, the lag should be relatively short. We would expect the longest lag and the widest technology gap to exist in those agricultural products in which the transfer of information and knowledge is in the "Stage IV" level. Agricultural development, at the present time, appears to reflect technology gaps which have been so determined.

Technology transfer of the easiest sort appears to have been limited to relatively few agricultural commodities. For a few countries, technical change in sugarcane, rice, and a number of the tropical crops has been transferred without extensive Stage IV-type research activity. These transfers have been accomplished with limited research activity. In a few additional cases, such as the spread of open-pollinated corn in Thailand, the transfer has involved some extension activity including added investments in clearing, draining, and irrigating new lands.

However, for most major crops the transfer depends on the existence of research organizations capable of performing Stage IV-type research. Generally, research organizations with this capability are scarce in the less-developed economies. Exceptions in sugarcane and bananas have been noted. The rice breeding effort in Taiwan and research effort in other tropical crops are also exceptions.

The technology gap for many of the major feed and food grains exists largely because good Stage IV research organizations do not exist in many less-developed countries. This gap has been widening for many years as the research organizations of the developed countries have continuously generated new technology and technical change which has not been transferred to the less-developed countries.

The efforts of the developed countries, particularly the United States, to foster the transmission of agricultural technology to the less-developed nations have not been particularly successful. Where the United States government has failed in this respect however, the Ford and Rockefeller Foundations have partially succeeded.[33/] The Rockefeller program in Mexico and the International Rice Research Institute (IRRI) in the Philippines are examples of the kinds of research organizations which are essential to the closing of the technology gap.

In addition to the Mexican and IRRI programs, a number of other efforts are underway. It appears that Stage IV research activity is now being activated on a much broader basis. The results of these efforts will be a narrowing of the technology gap that presently exists. In some crops it is possible that the gap is already diminishing. In others, the gap may yet widen. However, we expect that efforts to expand Stage IV research activities in agricultural technology will be successful enough to stimulate a "catching up" phase by the less-developed economies. This development of an international technology gap followed by its later reduction is not peculiar to agricultural products.

There are important implications to this catching up phase for both world trade and individual country gains from trade. It is difficult to speculate in detail about the specific shifts in trade, but evidence from all three cases in this paper indicates that shifts in technology levels clearly do affect trade patterns. We expect the less-developed countries, for example to become more self-sufficient in the production of certain feed and food grains. Some of the major importers among less-developed nations may shift to an export status in the relatively near future. The food aid and surplus-disposal programs of the United States, Canada, and Western Europe probably will be re-examined as many of the developing countries expand their own production with newly-developed technologies.

This catching up phase due to international transmission of technology generally will result in an improvement in the welfare of the less-developed countries as they improve their competitive position in world markets. Those developed countries which are presently exporters enjoying a long lead in technology probably will experience a decline in their competitive position. We do not see serious overall welfare considerations arising from this change since it represents improvement in the welfare of poorer nations relative to rich nations. Nevertheless, the pressure from developed-country producers for protectionist trade policies to maintain present trade patterns and price levels will probably be intensified.

Footnotes

*/ Minnesota Agricultural Experiment Station, Scientific Journal Paper No. 6718.

**/ The authors are Assistant Professor, Associate Professor and Professor, respectively, in the Department of Agricultural Economics, University of Minnesota.

1/ The authors are indebted to Mr. John Galstad, Department of Agricultural Economics, University of Minnesota, for assistance in the statistical tabulations and analyses of this section.

2/ The canesugar industry was a key part of the colonial empires of the nineteenth century. Slavery in the British West Indies was also integrally related to the production of sugarcane. For documentation see [4, 5, 34, 40].

3/ Prior to that time cane plants reproduced asexually except for rare instances of sexual reproduction in wild canes. Asexual reproduction is still the means of reproducing all commercially grown cane. Portions of the cane plant (usually the upper portion of the stalk) are planted and new plants grow from these segments.

4/ The opportunity to reproduce cane both sexually and asexually is important in sugarcane breeding. A successful cross between two cane plants may produce numerous seedlings. A single superior seedling can be reproduced asexually and create a completely new variety. Testing and selection of superior seedlings from thousands of candidates is a major activity in modern cane breeding.

5/ This problem continues to plague cane breeders. Modern varieties tend to undergo a deterioration in yield capability after several years of commercial production. New diseases continually make inroads on the old varieties. /5/

6/ Also an important Stage II station.

7/ This calculation adjusts for shifts in European and non-European grower percentages and a reduction in the number of ratoon crops (crops grown from the regrowth of the cane plant after cutting -- as many as 5 or 6 ratoon crops were grown). Since yield declines with the number of ratoon crops harvested, an adjustment was made for the differential age of the Uba cane being phased out and the new varieties being planted. The ratooning, of course, saves the expense of planting cane. It is a factor which slows down the speed of adoption of new varieties.

8/ The 28 percent is calculated from actual yield comparisons of old and new varieties under similar production conditions.

9/ Indonesia (Java) experienced a yield decline after the 1930-40 period and sharp export reduction beginning in the 1930's and continuing until 1950 when both yields and exports began to increase. Many factors account for this pattern. Prior to the late 1930's Java was second only to Cuba as a sugar exporter and ranked third in production behind Cuba and India. Java and Hawaii had the world's highest sugarcane yields in the 1930's. Today yields in Java are less than half those of Hawaii. Java was acknolwedged to have the world's most efficient and modern processing industry in 1930. The depression of the 1930's coincided with relatively high production levels for sugar, (to a considerable degree induced by Java-bred canes). Java as the world's major "free" market supplier was forced to cut back exports substantially in 1933. She was not favored in the International Sugar Agreement developed at this time. Aware of the expansion in world supplies as a result of the Java varieties, the government attempted to prevent the release of any new varieties outside of the country. War and Japanese occupation followed the depression. Many of the processing mills were destroyed during this period. From 1945 to 1949 internal revolution took place. This was partially directed against the sugarcane-producing industry which was an integral part of the "dual" structure which existed prior to the war. As a result, by 1950 the processing industry was almost entirely destroyed, cane fields had reverted to jungle and other crops, and what surely was one of the most outstanding agricultural experiment station in history was closed. /5, 9, 34, 40, 45/

10/ Cuba is the only major cane-producing country to have a relatively weak experiment station. Only two commerically-produced varieties have originated there. One of these pepe cuca, is of unknown parentage and was produced by an unknown breeder. /44/

11/ Factors other than varietal change will affect yields, of course. Yield increases often are due to the interaction of increase in fertilizer use, irrigation, and other inputs with new varieties. It is difficult to measure the extent to which the yield changes were due to new varieties, but it would appear to be the major factor.

12/ Most of the experiment stations for other agricultural crops have not been privately financed because producer groups have been too difficult to organize and no individual producer is large enough to capture the benefits from research.

13/ All sugarcane research costs in the South African experiment station to 1945 (the ending data of the period of introduction of Stage II and III varieties from other countries), accumulated at an interest rate of 6 percent, amounted to 830,782 Rand. After subtracting seed costs associated with the new varieties a stream of annual benefits can be calculated from the supply function shift using a technique developed by Griliches. [12] These measured annual benefits also were accumulated at 6 percent to 1945. Assuming no further increases in yield, an annual flow of benefits was calculated by assuming the 1945 yields to remain constant and adding to this flow 6 percent of the accumulated benefits as of 1945. The result of the annual benefit flow was 2.47 times the accumulated research costs of 1945. This could be interpreted as a 247 percent rate of returns to investment in research. But, for reasons discussed above, such an interpretation may not be correct. [1, 8, 7, 11, 39]

14/ If one makes the same calculations and assumptions for the South African case as in footnote 13 except for the 1945-60 period when the station was contributing Stage IV varieties to the conomy, the annual benefit flow is 1.2 times the accumulated costs to 1960. This might more legitimately be interpreted as a 120 percent rate of return to investment in research. Of course, if one chooses to express this as an "internal" rate of return, it would be much lower. The assumption that yields would remain constant is not fully justified. Yields tend to decline over time with new varieties. Even after making additional adjustments of this sort, we would have to conclude that the South African investment in research has yielded a very high return.

15/ Much of the background material for this section is drawn from H. B. Arthur, J. P. Houck, Jr., and G. L. Beckford Tropical Agribusiness: Structures and Adjustments -- Bananas, Harvard Business School, (now in press). That study as well as this discussion relies heavily on data kindly provided by private trade sources, especially United Fruit Company and Standard Fruit and Steamship Company. Professor H. B. Arthur of the Harvard Business School offered helpful suggestions on this section of the paper.

16/ Private producers tied to one or the other of the major companies through production contracts, credit arrangements, and disease control programs are considered as part of company production for this discussion.

17/ Further research and field experience has shown that sigatoka control can be achieved through application of either an oil-based or a low volume organic fungicide spray delivered by aircraft or knapsack sprayer. This development, occurring in the 1950's, has eliminated the need for the cumbersome water-spray installations of the earlier era.

18/ During this period; Guatemala, Honduras, Costa Rica, and Panama accounted for about 95 percent of all Central American banana shipments.

19/ In 1955-57, bananas accounted for 13, 34, 54, 72 percent of export revenues for Guatemala, Costa Rica, Honduras, and Panama, respectively, see Table II.4.

20/ The term "new varieties" is not meant to suggest that the adopted varieties were genetically or botanically new. They were simply new to commercial production and export from these areas.

21/ With Gros Michel, the major companies expected to lose an average of 20 to 25 percent of their mature banana plants annually due to blow-downs.

22/ Legal restrictions prevent the major importing companies from operating their own ripening and distribution facilities. An ownership transfer occurs for virtually all U.S. banana imports at dockside.

23/ This assumes that the availability of both stem and boxed fruit from the relatively open market in Ecuador kept import prices reasonably close to competitive levels.

24/ There are other economic and political considerations, beyond the scope of this discussion, which also favor banana expansion in these countries.

25/ The authors are indebted to Yujiro Hayami, Ramon H. Myers, James I. Nakamura and Henry Rosovsky for review and criticism of an earlier draft of this section of the paper and to Aida Recto and John Sanders for assistance in the statistical tabulation and calculations.

26/ "The years after 1920 were difficult years for Japanese agriculture. Cheap rice began to be imported from Korea and Formosa, where rice cultivation had been encouraged by the Japanese government following the food shortage of World War I and the rice riots that resulted in 1918." /36, p. 334/

27/ The general pattern described above has been challenged by Nakamura. /27, 28/ Nakamura argues that agricultural production was underestimated at the beginning of the Meiji period and that the gradual improvement of production estimates between the mid-1870's and the early 1920's has inflated the rate of output and productivity growth during the first "epoch". It appears that Nakamura's criticisms are stimulating review and revision of the "official" estimates. However, these revisions will not destroy the generalizations about the four broad "epochs" described above. For further discussion of this issue see the following references. /15, 22, 29/

28/ Early efforts to expand rice production on Hokkaido were also relatively unsuccessful. It was not until after World War II that efforts to achieve high and relatively stable average yields were successful in Hokkaido. /31, pp. 319, 435-478/

29/ The early Japanese efforts to improve rice yields in Taiwan emphasized selection and diffusion of the highest yielding native *indica* varieties. In spite of a large reduction in the number of inferior varieties grown and substantial diffusion of superior varieties, the average yield showed only modest gains. Early efforts to introduce *japonica* varieties from Japan were not successful. Even after substantial modification in cultural practices, the high yield potentials of the *japonica* varieties were only partially realized under

Taiwan conditions. Efforts were then directed to breeding varieties which combined the desirable characteristics of the introduced *japonica* varieties (high fertilizer response, short growing period, nonsensitivity to photo period, and better quality) with the resistance to disease and the superior adaptation to the local ecology of the native *indica* varieties. The new varieties developed in Taiwan using japonica genetic materials are referred to as ponlai (or horai) varieties.

The first *ponlai* variety was introduced commercially in 1922 when it was planted on 414 hectares in the Hsinchu region. An exceptionally high yield of 2,517 metric tons of brown rice per hectare was achieved. Later the planted areas were increased and extended to the Taipei and Taichung regions. With the diffusion, average yield declined. After 1925 an outbreak of rice blast disease, to which the new varieties were highly susceptible, sharply reduced the *ponlai* yields. Beginning in 1930 other ponlai varieties with greater resistance to the rice blast disease were introduced. Over 20 years had elapsed between the introduction of the first *japonica* varieties and the development of the *ponlai* varieties which possessed sufficient advantage over the local varieties to justify rapid diffusion. /17, pp. 331-333/

30/ The actual average rate of rice production growth in the period between 1900-03 and 1919-22 was 1.3 percent per year. The "isolation model" suggests a similar growth rate of 1.3 percent for the 1919-22 to 1937-40 period when imports were presumed to be prohibited. The actual production growth rate was 1.1 percent per year in the presence of imports from other nations. Years before 1900 were omitted from this comparison in order to avoid the data problems raised by Nakamura. /27, 28/

31/ The results presented here should be treated more as the statement of a hypothesis than as a final conclusion. Work is currently underway by Yujiro Hayami and V. W. Ruttan to test the colonial trade import hypotheses more vigorously.

32/ In terms of the sugarcane terminology, the banana breeding effort would be classified as Stage I research since it involved the selection of natural varieties.

33/ The economic development efforts associated with the foreign aid and technical assistance programs of the United States have, until recently, given agricultural development low priority. The viewpoint was that the key to economic growth is the development of industrial and urban service sectors, even at the expense of agriculture. This policy of attempting to develop an economy by making it look like a developed economy has not been particularly successful. As interest now turns to searching for "cheap sources of growth" or high-payoff investments, more attention is being paid to the agricultural sector. The establishment of first-rate, Stage IV research stations is likely to be a very high-payoff investment in most of the less-developed countries.

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