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Technical Change & Agricultural Trade: Three Examples—Sugarcane, Bananas, and Rice

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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 advanced 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 under-

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pin the development programs of many poorer nations. Farm income and employment in many developing nations are major components of over-all 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 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.

Section I 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. Section II on the bananas 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. Section III on the 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 period before World War II. 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 those 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. Intercountry and intracountry 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. In this table, as throughout this paper, quantitative measures of "sugar" refer to material with 96 per cent sugar content. The relative position of a number of countries has changed considerably over time. The increased importance of production in 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, the 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 originated in India, New Guinea, and Java, and in most cases, planters relied on a single variety for many years. Occa-

[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.

TABLE I.1

National Sugarcane Yield and Production Averages for Selected Five-Year Periods

(production in thousands of short tons; yield in short tons per acre)

Area	1910–14		1923–24		1928–32	
	Production	Yield	Production	Yield	Production	Yield
Brazil	333	–	860	–	956	–
Cuba	2,287	14.5[c]	4,345	19.3	4,389	18.6
India	2,699[a]	11.3	3,563[a]	11.0	3,561[a]	12.4
Mexico	163	–	175	30.2	235	20.5
Australia	216	17.3	409	16.8	450	16.9
Philippine Islands	294	–	502	–	968	20.4
Argentina	194	11.6	260	13.2	410	13.6
Hawaii	567	40.7	614	43.3	951	60.1
United States	311	15.8	229	9.4	149	15.0
Taiwan	192	11.8	450	16.1	869	29.3
South Africa	88	–	181	8.8	312	20.5
Puerto Rico	363	–	414	16.6	795	25.3
Peru	203	22.4	344	24.3	441	40.5
Indonesia	1,513	41.2	1,985	46.5	3,010	56.4
British West Indies[b]	218	–	231	9.6	348	24.0
Dominican Republic	105	–	231	–	419	–
Mauritius	234	15.6	238	14.5	241	15.2
Egypt	67	18.8	93	–	123	35.0

Source: *Yearbook of Agriculture*, USDA, Washington, various issues, 1925-35; *Agricultural Statistics*, USDA, Washington, annual issues, 1936-66; *International Sugar Situation*, USDA, Bureau of Statistics, Bulletin 30, 1904; *Production Yearbook*, FAO, Rome, various issues, 1948-66; *Annual Report*, Bureau of Sugar Experiment Stations, Queensland, annual reports, 1900-64: *South African Sugar Yearbook*, Durban, 1935, 1948-49, 1961-62; *International Yearbook of Agricultural Statistics*, Rome, various issues, 1910-46: *Indian Sugar Manual*, Kalyanur, India, 1962, 1963-64.

[a] Expressed in short tons of low-grade gur.

[b] Countries included are Antigua, Barbados, British Guiana, Trinidad, Tobago, St. Christopher, St. Lucia, St. Vincent.

[c] 1913-14 only.

[d] 1940-42 only.

[e] 1940 only.

[f] 1960 only.

[g] 1963 only.

1938–42		1948–52		1958–62		1963–67	
Production	Yield	Production	Yield	Production	Yield	Production	Yield
1,333	17.1	1,775	17.4	3,726	18.8	5,329	19.8
3,200	17.2	6,378	17.0	6,030	17.0	4,950	16.2
5,508[a]	11.5	1,548	13.1	3,364	15.3	4,515	20.8
398	22.4	789	23.1	1,665	26.4	2,319	27.0
746	20.3	865	23.6	1,395	27.5	1,643[g]	36.2
1,146	22.6	912	20.3	1,626	26.7	1,584	19.3
509	13.4[d]	687	14.9	950	17.0	1,422	23.0
935	65.1	979	76.4	1,048	90.0	1,275	98.7
460	19.3	517	19.5	707	24.5	1,104	25.3
1,357	–	683	27.3	931	33.7	1,100	38.6
534	26.3	612	25.1	1,140	35.3	1,002	35.8
998	32.4	1,264	29.8	1,051	30.4	897	30.6
482	52.6	544	60.0	884	70.4	882	64.2
1,718	61.5	356	40.0	780	49.5	854	39.1
502	17.6	617	38.1	808	39.4	801	36.4
484	19.0[e]	590	–	1,012	19.5[f]	800	22.5
337	19.8	490	–	535	24.6	732	24.0
188	–	215	32.8	369	42.6	465	40.0

sionally 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 the experiment station in Java, sugarcane seedlings

[2] The cane sugar 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].

were first produced through a process of sexual reproduction[3] [5, 40, 34]. This was of great importance since it opened the possibility of crossing varieties. The cane plant ordinarily does not flower and produce seedlings readily. Flowering in the cane plant is induced by temperature and light control, and few experiment stations were successful in their attempts to produce seedlings in the early days of cane crossbreeding.[4]

Several experiment stations had notable successes in the development of the first new varieties. The Java station (Proefstatien Oost Java) 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 grandparent was the first important Java variety, P.O.J. 100. 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

[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].

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 period from 1920 to 1940 the Coimbatore station in India also produced a number of important varieties which incorporated disease resistance and high yield. 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.

STAGE IV—BREEDING FOR SPECIFIC SOIL AND CLIMATE CONDITIONS

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 one hundred 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 areas.

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 over-all importance of each variety in the major countries of the world during the twenty-five-year period. Argentina and the Philippines are the only major producing countries not included in this calculation.

Almost all the major varieties during this period were bred prior to 1940. Most are examples of the third stage in breeding progress. The widespread planting of the Java (P.O.J.) and Indian (Co.) varieties is

TABLE I.2

Per Cent of Sugarcane Acreage Planted to Varieties Developed by the Experiment Station of Selected Areas: 1930–65

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

Source: *Annual Report,* Bureau of Sugar Experiment Stations, Queensland, Australia, 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.

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 of New Guinea, had any commercial importance during this period. The P.O.J. 2364 variety was never a significant commercial variety, but it was important as a parent to P.O.J. 2878 and several other varieties.

Table I.4 indicates the importance of the Coimbatore and Java stations in the generation of new varieties. The Java station has been especially productive of parent and grandparent varieties. Almost all 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.

[6] Also an important Stage-II station.

International transmission of varietal changes

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 in South Africa began in 1849. Prior to 1880 several wild varieties imported from Java, Mauritius, and India 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 principal 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 per cent in 1933–34 to 95.5 per cent in 1942–43, nine years later. An analysis of yield increases indicates that up to 1945 the new varieties introduced outyielded the old Uba variety by about 27 per cent.[7]

By 1947 the experiment station had produced its first South African variety, N:Co. 310 (the first N:Co. varieties were bred in India but the selections for commercial planting were made in South Africa). As

[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 five or six 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.

TABLE I.3

Important Sugarcane Varieties: 1940–64

Variety	Station	Date Bred	No. of Countries where Produced Commercially	Role in Production: As Variety Quantity[a]	As Variety Rank	As Parent Quantity[a]	As Parent Rank	As Grandparent Quantity[a]	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		
Badila	(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

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		
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	Demerara					3.7	8
Co 205	India					3.3	12
Co 285	India					2.6	15

Source: *Yearbook of Agriculture*, USDA, Washington, 1936, pp. 561-624; *Proceedings of the Twelfth Congress*, International Society of Sugarcane Technologists, New York, 1967, pp. 844-54; *Agricultural Statistics*, USDA, Washington, various issues; J. T. Rao and Y. Vijayalakshmi, *Improved Canes in Cultivation*, New Delhi, 1967.

[a]Total production in millions of short tons, 1940-64.

TABLE I.4

Varietal Production of Various Sugarcane Experiment Stations: 1940–64

(millions of metric tons)

Experiment Station	Varieties		Variety Parents		Variety Grandparents	
	Production[a]	Rank	Production[a]	Rank	Production[a]	Rank
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

Source: *Yearbook of Agriculture*, USDA, Washington, 1936, pp. 561-624; *Proceedings of the Twelfth Congress*, International Society of Sugarcane Technologists, New York, 1967, pp. 844-54; *Agricultural Statistics*, USDA, Washington, various issues.

[a]Total production, 1940-64.

shown in Table I.3, this variety came to be commercially produced in four other countries, most notably in Taiwan (a rarity for a Stage-IV cane variety); and from Table I.2 it can be seen that it, along with several additional N:Co. varieties, occupied 78 per cent of the planted acreage in South Africa by 1960. 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 per cent 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 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, but only a limited number of these varieties are transferred to other countries. An important element of international transmission of technological change remains, however. Genetic materials such as 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 is exchanged.

Intracountry 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. As one would

[8] The 28 per cent is calculated from actual yield comparisons of old and new varieties under similar production conditions.

expect in South Africa and in most other countries, the organizations of planters which support the experiment stations adopt the new varieties developed by these stations rather quickly. 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 per cent) just eight years later. N:Co. 310 was introduced in 1948–49 and reached its maximum proportion of planted acreage (60 per cent) 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 per cent) approximately ten years after introduction. In Puerto Rico, BH 10-12, introduced in 1920, reached a maximum proportion of approximately 25 per cent fifteen years later. However, PR 980, a locally bred variety introduced in 1955, had reached a proportion of almost 50 per cent by 1965.

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. Planters with small holdings 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 per cent and 1 per cent of the acreage of Andra Pradesh. Seven years later the proportions were 14 per cent and 8 per cent, respectively [18].

Changes in sugar trade

Table I.5 presents trade data for sugar. It should be noted that roughly 40 per cent of the world's sugar production is from sugar beets.

TABLE I.5

TABLE I.5

Net Exports and Imports of Sugar by Countries, Selected Years[a]

Country	Annual Average (thousands of short tons)						
	1909-13	1922-23	1928-31	1937-39	1948-52	1958-62	1963-67
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[b]	2,296	1,318	13	43	165
Argentina	-52	-54	9	31	-1,626	59	71
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

Notes to Table I.5

Source: *Yearbook of Agriculture*, USDA, Washington, 1925-35; *Agricultural Statistics*, USDA, Washington, 1936-66; *International Yearbook of Agricultural Statistics*, Rome, various volumes 1910-46.

[a]Exports are positive numbers; imports are negative.

[b]1924.

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 or quota system, or both, 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.

Tables 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 per cent to 41 per cent 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 per cent 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 per cent in this period.[9] Their average annual exports increased by 2,079,000 short tons, 44 per cent of their 1950 average production. Only the Philippines had an export increase (65 per cent) on 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) intercountry agreements, (2) shifts in the position of competing crops, and (3) changes in the degree of protection offered domestic beet sugar industries.[11]

[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 acknowledged 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 stations 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.

Benefits from technological change in the production of sugarcane

The yield increases due to new sugarcane varieties have been substantial and have afforded great benefits to producing and consuming countries. The allocation of these benefits to the economic activity which produced them is difficult for several reasons. As this paper has shown, several different types of activity have been involved. The development of the Stage-II and -III varieties has clearly been important. These benefits must be allocated between the research effort which generated the varieties and the research, testing, and extension effort which speeded up their international transmission to countries other than the originating country.

The early Stage-II varieties were transferred easily, and little formal economic activity was associated with their transfer. New cultural practices were not required. Information regarding the relative profitability of producing the new variety was required, but informal information channels were available through growers' organizations to facilitate this transmission. Producer organizations have been keenly aware of their competitive position in world sugar trade and of their relative comparative advantage. This is one reason that substantial private effort to obtain information about new varieties took place. It also explains why in most countries producers have been willing to finance their own experiment stations privately.[12]

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 per cent. If one wished to attribute this yield increase to the experiment station efforts, a handsome return to such investment could be calculated.[13] But only part of the value of this yield increase

[12] Most 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 of the data from the period of introduction of Stage-II and -III varieties from other countries), accumulated at an interest rate of 6 per cent, 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

should be attributed to the experiment station effort since the varieties would eventually have been adopted without it. Also some of the experiment station effort was an investment in a Stage-IV breeding program.

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, and shifts in the production function and supply curve 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 exporting 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

shift using a technique developed by Griliches [12]. These measured annual benefits also were accumulated at 6 per cent 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 per cent of the accumulated benefits as of 1945. The resultant annual benefit flow was 2.47 times the accumulated research costs of 1945. This could be interpreted as a 247 per cent 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 economy, the annual benefit flow is 1.2 times the accumulated costs to 1960. This might more legitimately be interpreted as a 120 per cent 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.

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 depression years and Java bore the brunt of the reduction in world trade.

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 the devastating inroads of the Panama disease in bananas. In the twenty-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 postwar setting

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

Banana exports from Central America dominated the world trade

[15] Much of the background material for this section is drawn from H. B. Arthur, J. P. Houck and G. L. Beckford, *Tropical Agribusiness: Structures and Adjustments—Bananas*, Harvard Business School, 1968. 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.

TABLE II.1

World Exports of Bananas from South America, Central America, and the Rest of the World; Five-Year Averages: 1935–39 to 1963–67
(thousands of metric tons)

Region	1935–39	1948–52	1953–57	1958–62	1963–67[a]
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	971.8	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

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

[a]Includes preliminary data for 1967.

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

[c]Ecuador, Colombia, Brazil.

picture, accounting for about half the total during the period 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 reactivating and adding to their war-idled resources. These two U.S. firms—United Fruit was by far the larger—had operated plantations, export facilities, and a host of community services (roads, railroads, schools, hospitals, etc.) in Central America since the early 1900's, and their combined banana output accounted for all but a small portion of Central American production.[16] Together, United Fruit and Standard Fruit held 90 per cent to 95 per cent of the U.S. import market during the period 1948–52.

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 in-

[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.

definitely 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, botanically, the banana is a giant herb growing from an underground rhizome, crossbreeding and other known techniques of producing new varieties with 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 reinfection 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 period after World War II when banana production began to exceed prewar 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 925,000 acres of banana land have been abandoned, mostly because of Panama disease. This averages about 14,000 acres per year. These average annual abandonments amounted to about 10 per cent 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 25,000 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

The period 1948–52 was 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, and the stagnation in Central American exports in this period is indicated by the data in Table II.1. Abandonments, due principally 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 12,000-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 forty years.[18]

TABLE II.2

Areas of Cultivation of Exportable Bananas in Central America: Five-year Averages 1948–52, 1953–57, and 1958–63

(thousands of acres)

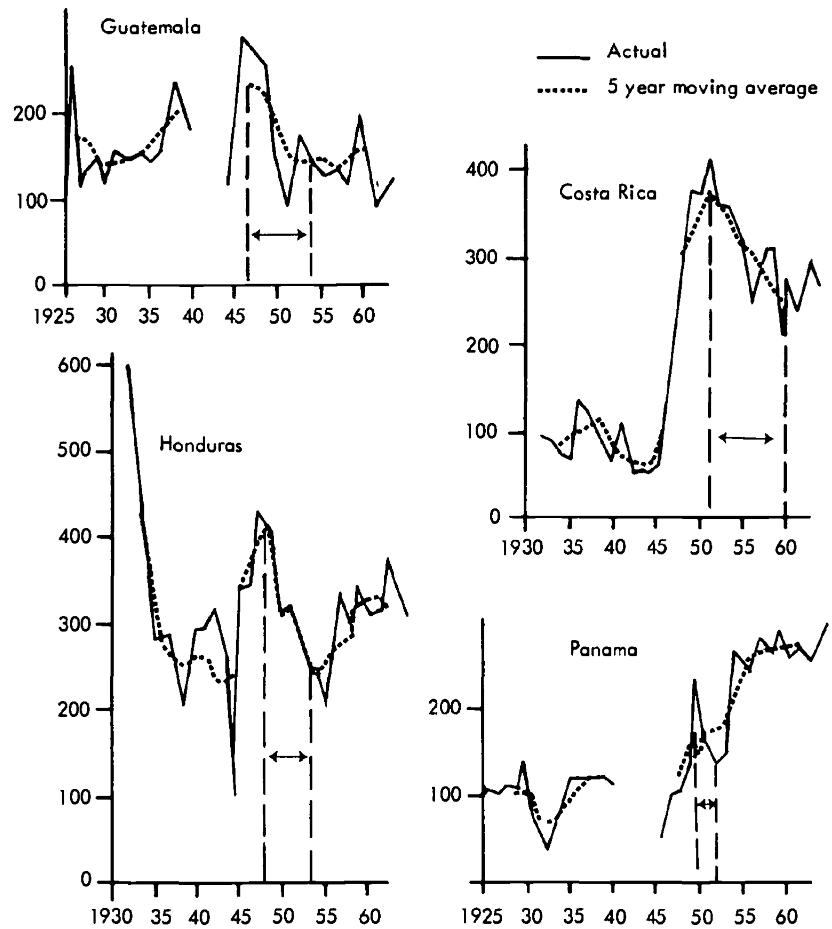
Country	1948–52	1953–57	1958–63
Guatemala	46.7	39.3	31.3
Honduras	55.8	53.5	43.5
Costa Rica	42.8	39.0	30.6
Panama	19.2	26.0	30.8

Note: Major companies and their associated growers only.
Source: Data supplied by major fruit companies.

[18] During this period, Guatemala, Honduras, Costa Rica, and Panama accounted for about 95 per cent of all Central American banana shipments.

FIGURE 1

Volume of Banana Exports from Four Central American Countries, 1925–64
(metric tons)



Note: Breaks in Panama and Guatemala indicate that no information is available for the relevant period.
Source: U.N. Food and Agriculture Organization

The drop in exports that can be attributed almost entirely to inroads of Panama disease is shown between the vertical dotted lines. Even in Panama, where the production and export trend generally increased 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, Table II.1 shows that exports from other sources expanded substantially. Banana exports from South America, Ecuador and Colombia, are most relevant in this expansion, because almost all the other major banana exporters operate under the protection of preferential arrangements with major importers (e.g., Jamaica and the Windward Islands 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.

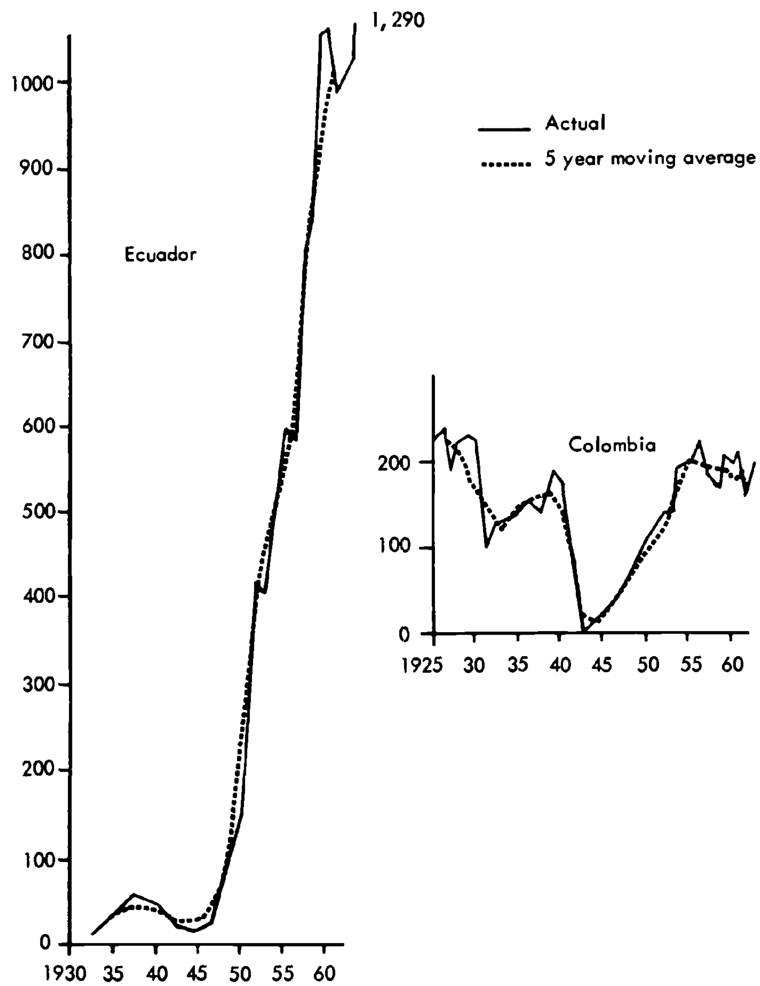
As mentioned previously, both Ecuador and Colombia produced mainly the Gros Michel variety but were relatively free of Panama disease in this period. Colombian bananas were shipped mainly to Western Europe, and up to two-thirds of Ecuador's exports came to the United States where, by 1959, they accounted for over 40 per cent 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, abundant land, and government encouragement fueled this tremendous growth in output. 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 Government of Ecuador 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 producing-marketing companies dropped to about 70 per cent 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.

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,

FIGURE 2

Volume of Banana Exports From Ecuador and Colombia, 1925–64
(metric tons)



Source: U.N. Food and Agriculture Organization

and elsewhere. Without a major cost-reducing shift in banana production technology, the invested capital, land resources, production knowledge, and skill in quality control 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 resistance to change within the companies. The firms' producing, shipping, and marketing divisions knew precisely how to grow, transport, and merchandise Gros Michel. Much would have to be relearned if new varieties were adopted.

Resistance to a variety switch gave way faster in the smaller Standard Fruit and Steamship Company, due perhaps to a major management change in 1953 and the existence of smaller disease-free land reserves under company control in producing areas. By 1957, Standard had planted fourteen to fifteen thousand acres in bananas of the Cavendish group. These varieties were selected by researchers from those available in the Caribbean, 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, a member of the Cavendish group, which was being grown on the firm's experimental farm in Honduras. This plant had 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

[19] In 1955–57, bananas accounted for 13, 34, 54, 72 per cent of export revenues for Guatemala. Costa Rica, Honduras, and Panama, respectively (see Table II.4).

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 disastrous for them. On the other hand, the shift to Cavendish-type bananas already had occurred in the West Indian banana industries of Jamaica, Windward Islands, Guadeloupe and 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 over-all 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 "blowdowns" 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.

However, the skeptics had correctly foreseen a major problem with the new varieties. Bananas of the Cavendish group were not well suited to the commercial methods of handling and shipping then in use. In

[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] The major companies expected to lose an average of 20 to 25 per cent of their mature Gros Michel banana plants annually due to blowdowns.

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 are the 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 revolutionizing banana handling in virtually all international markets.

Tropical boxing

During the reign of the Gros Michel in Central and South America, almost 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.

[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.

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 functions and part or all of the sorting and grading function, but 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 the typical rail, truck, and warehouse machinery, and the new variety fruit is less likely to be bruised in boxes. 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 nonreturnable, one-way cardboard carton. From the producing company's viewpoint, more fruit could be salvaged all along the way than under the old system where 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 per cent 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 United Fruit Company, which was still shipping Gros Michel in 1962, was forced to develop its own tropical 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. Table II.3 shows that 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

Percentage of U.S. Imports of Bananas Arriving as Boxed Fruit: 1960–66

Year	Per Cent in Boxes
1960	2
1961	15
1962	30
1963	50
1964	85
1965	96
1966	99

Source: Estimated from data supplied by major importers.

The trend toward tropical 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, and, as a result, 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 tropical boxing in order to maintain their previous market position. Several intermediate production processes—cutting, sorting, and boxing—shifted from the developed importing nation to the less developed producing and exporting nations, and new box-making plants came into operation in Central America and Ecuador. Furthermore, the nature of the actual product moving in international commerce was altered from an essentially unprocessed primary product to a commodity substantially closer to the final product sold to consumers.

Economic impacts of innovation

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 predisease 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 the disease-free Gros Michel output relationship.

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 the slow growth of 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 preeminent position in the world banana trade.

Tropical boxing of bananas was undertaken initially to facilitate the shift to new varieties. The 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 rules indicates it is a net cost-reducing procedure for bananas moving into the relatively sophisticated marketing channels of North America and Western Europe.

Some calculations for 1963, when stem and boxed bananas shared the U.S. market about equally, indicate that on an equivalent basis and in terms of usable fruit, boxed banana import prices received by major importers were about 13 per cent 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 United States 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, 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 period 1960–66. 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—the shift in production to new or improved varieties and the tropical boxing technology—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 slowdown of the growth in export volume 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 reduced that nation's dependence on bananas somewhat since the peak period in 1959–61 and helped to

[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.

TABLE II.4

Value of Banana Exports and Per Cent[a] of Total Exports Accounted for by Bananas in Four Central American Countries and Ecuador

Country	Annual average 1955–57	1959–61	1964–66
Costa Rica			
Banana exports (mil. dollars)	26.1	20.1	28.6
Per cent of total exports	34	25	24
Guatemala			
Banana exports (mil. dollars)	15.5	15.3	6.5
Per cent of total exports	13	14	3
Honduras			
Banana exports (mil. dollars)	34.0	31.4	53.1
Per cent of total exports	54	46	44
Panama			
Banana exports (mil.dollars)	24.3	20.6	37.8
Per cent of total exports	72	67	48
Ecuador			
Banana exports (mil. dollars)	63.4	86.4	90.1
Per cent 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.

[a]Percentages are based on three-year totals.

offset the shift of comparative advantage in bananas back to Central America. Banana earnings in the 1960's generally increased 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 abandonments caused by Panama disease.

Dependence upon bananas for foreign exchange, while still extremely important for several of these nations, especially Ecuador, Panama, and Honduras, declined for all these countries after 1959–61 and for all but Ecuador after 1955–57. In the late 1960's it appeared that much of the future growth in the production and boxing of bananas would be focused in Honduras, Panama, and Costa Rica, because these nations seemed to provide the best over-all 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 were engaged in major production-expanding programs with disease-resistant varieties in Honduras. United Fruit, the only major exporter of Panamanian bananas, was expanding Valery output on its fully-owned plantations. In addition, United was being relatively successful with an expanding associate producer program in Central America. (Associate producers grew bananas under contract with United Fruit Company. They received basic services, facilities, and credit from the company, but had to follow specified production practices laid out by the company.) Substantial expansion of production in Costa Rica was being planned, especially by Standard.

Banana prices in several major importing nations drifted downward after the late 1950's. Retail prices in the United States, Canada, and West Germany have dropped about 10 per cent since 1958; "real" prices of course dropped further [42, p. 22], [41, p. 8]. Increased supplies due to the new varieties and the adoption of tropical boxing have intensified the long-run tendency for supplies to increase faster than demand, so that at least part of these price declines can be attributed to technological changes as well as to increased plantings and better management. Measuring the price impact of these changes is difficult, but perhaps the following suggests the magnitudes.

FAO projections of world banana supplies for 1965–70 foresaw an increase of about 40 per cent in the period [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

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

Ecuador, probably would have expanded faster in the absence of Central American competition 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 per cent of 1965–66 levels. That is, in the absence of any expansion in Central America and assuming all other export availabilities remain as projected, the retail banana prices in world markets would average in 1970 some 10 per cent below 1965–66 levels. When the projected increase in Central American supplies is added, then average retail prices some 30 per cent below 1965–66 levels are required to balance amounts demanded with projected export availabilities [26, Table III.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 from the expected rise in average banana quality resulting from the increased use of 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.

III. RICE

In this section [25] 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 hypotheses advanced by several Japanese scholars: the transfer of rice production technology from Japan to Taiwan and Korea was responsible for the expansion of exports

[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.

TABLE III.1

Annual Growth Rates of Output, Inputs, and Productivity in Japanese Agriculture: 1882–1957
(per cent per year)

	Phase I (1882-1917)	Phase II (1917-37)	Phase III (1937-47)	Phase IV (1947-57)
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

Source: Saburo Yamada [47], pp. 371-413.

from the colonial areas to metropolitan Japan; 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 was not

[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].

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 one hundred years of "modernization" following the start of the Meiji period in 1868. As outlined in Table III.1, four main periods, sometimes called "technical epochs," are frequently identified. As indicated in Tables III.2 and III.3, the first was

TABLE III.2

Paddy Rice Yields in Japan, 1873–1922; Five-Year Averages of Official and Corrected Figures

	Official Estimates[a]	Yamada - Hayami Estimates[b]	Nakamura Estimates[c] (1)	Nakamura Estimates[c] (2)	Nakamura Estimates[c] (3)
	Koku Per Tan of Brown Rice[d]				
Period					
1873–77	–	–	1.500	1.600	1.700
1878–82	1.166	1.264	1.519	1.636	1.721
1883–87	1.297	1.355	1.599	1.672	1.743
1888–92	1.428	1.425	1.651	1.709	1.764
1893–97	1.371	1.371	1.705	1.747	1.786
1898–1902	1.516	1.516	1.760	1.786	1.808
1903–07	1.626	1.626	1.817	1.826	1.831
1908–12	1.734	1.734	1.876	1.867	1.854
1913–17	1.843	1.843	1.937	1.908	1.877
1918–22	1.927	1.927	2.000	1.950	1.900
	Per Cent				
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, 228-30].

[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: 1900–40

	Production[a] (thousand metric tons)			Area Planted[b] (thousand hectares)			Yield per Hectare (kilograms)		
	Total	Paddy	Upland	Total	Paddy	Upland	Total	Paddy	Upland
Year									
1900–01	6,220	6,122	98	2,805	2,731	74	2,217	2,242	1,325
1901–02	7,037	6,929	108	2,824	2,745	79	2,492	2,525	1,366
1902–03	5,540	5,449	91	2,824	2,740	83	1,962	1,989	1,090
1903–04	6,971	6,872	99	2,840	2,755	85	2,454	2,494	1,162
1904–05	7,713	7,627	86	2,857	2,774	82	2,700	2,749	1,046
1905–06	5,726	5,637	89	2,858	2,783	74	2,004	2,025	1,195
1906–07	6,945	6,842	103	2,875	2,799	77	2,416	2,444	1,363
1907–08	7,358	7,238	120	2,882	2,804	78	2,553	2,581	1,531
1908–09	7,790	7,658	132	2,898	2,815	83	2,688	2,720	1,594
1909–10	7,866	7,732	134	2,914	2,827	86	2,699	2,735	1,545
1910–11	6,996	6,855	140	2,925	2,834	91	2,392	2,419	1,526
1911–12	7,757	7,602	154	2,949	2,852	97	2,630	2,665	1,599
1912–13	7,533	7,389	144	2,978	2,869	109	2,530	2,575	1,322
1913–14	7,539	7,374	165	3,005	2,886	118	2,509	2,555	1,392
1914–15	8,551	8,381	170	3,008	2,886	122	2,842	2,904	1,383
1915–16	8,389	8,189	200	3,031	2,907	124	2,767	2,817	1,607
1916–17	8,768	8,534	234	3,046	2,918	128	2,879	2,924	1,831
1917–18	8,185	8,015	170	3,058	2,928	130	2,677	2,738	1,309
1918–19	8,205	8,022	184	3,067	2,935	132	2,675	2,733	1,392
1919–20	9,123	8,887	236	3,079	2,943	136	2,963	3,019	1,741
1920–21	9,481	9,205	276	3,101	2,960	140	3,058	3,105	1,969
1921–22	8,277	8,055	222	3,109	2,968	141	2,662	2,714	1,572
1922–23	9,104	8,907	203	3,115	2,972	143	2,923	2,995	1,420
1923–24	8,317	8,120	197	3,121	2,982	139	2,664	2,723	1,411
1924–25	8,576	8,425	150	3,117	2,980	137	2,752	2,827	1,101
1925–26	8,956	8,716	239	3,128	2,993	135	2,863	2,913	1,768

1920–21	9,481	9,205	276	3,101	2,960	140	3,058	3,105	1,969
1921–22	8,277	8,055	222	3,109	2,968	141	2,662	2,714	1,572
1922–23	9,104	8,907	203	3,115	2,972	143	2,923	2,995	1,420
1923–24	8,317	8,120	197	3,121	2,982	139	2,664	2,723	1,411
1924–25	8,576	8,425	150	3,117	2,980	137	2,752	2,827	1,101
1925–26	8,956	8,716	239	3,128	2,993	135	2,863	2,913	1,768
1926–27	8,339	8,150	189	3,132	2,996	136	2,662	2,720	1,385
1927–28	9,315	9,083	232	3,147	3,013	134	2,960	3,014	1,731
1928–29	9,045	8,812	233	3,165	3,030	136	2,858	2,909	1,719
1929–30	8,934	8,802	132	3,184	3,050	134	2,806	2,886	979
1930–31	10,031	9,790	242	3,212	3,079	133	3,123	3,179	1,812
1931–32	8,282	8,098	184	3,222	3,089	133	2,571	2,622	1,383
1932–33	9,058	8,852	206	3,230	3,097	133	2,804	2,858	1,549
1933–34	10,624	10,439	185	3,147	3,022	124	3,376	3,454	1,484
1934–35	7,776	7,634	142	3,147	3,022	124	2,471	2,526	1,138
1935–36	8,618	8,414	205	3,178	3,044	134	2,712	2,764	1,528
1936–37	10,101	9,836	265	3,180	3,042	139	3,176	3,234	1,909
1937–38	9,948	9,766	182	3,190	3,044	146	3,130	3,208	1,246
1938–39	9,880	9,628	252	3,194	3,048	146	3,093	3,159	1,722
1939–40	10,345	10,052	292	3,166	3,016	150	3,267	3,333	1,942
Average									
1900–01 to 1909–10	6,916	6,811	106	2,858	2,777	80	2,419	2,450	1,322
1910–11 to 1919–20	8,104	7,925	180	3,015	2,896	119	2,688	2,686	1,510
1920–21 to 1929–30	8,839	8,627	207	3,132	2,994	138	2,821	2,881	1,505
1930–31 to 1939–40	9,466	9,251	216	3,186	3,187	136	2,972	3,034	1,571

Source: *Japan Statistical Yearbook*, Tokyo, 1949, p. 203; 1961, p. 90; 1964, p. 98.

[a]Converted from koku to metric tons at 150 kg. per koku.

[b]Converted from cho to hectares at .991736 ha. per cho.

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 was 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 of growth of land productivity. Yield increases (land productivity) accounted for approximately two-thirds of the growth of output and were achieved primarily through intensification of the "traditional" biological technology; that is, (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) land improvement projects—principally the replanting 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 used by the best farmers and in the best regions were developed during the 1880's. This effort was complemented by the development of prefectural (local) experiment stations in the 1890's. By the end of this first 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, which contributed to the expansion of the irrigated area and increased the precision of water treatment.

[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 [15, 22, 29].

TABLE III.4

Average Price Indexes for Brown Rice and the General Price Index in Japan: 1878–1912

(1893–97 = 100)

Period	Rice Price Index *(R)*	General Price Index (*G*)	*R/G*
1878–82	92.7	110.9	0.83
1883–87	57.9	81.0	0.71
1888–92	71.8	88.9	0.80
1893–97	100.0	100.0	1.00
1898–1902	129.9	127.3	1.02
1903–07	156.6	152.6	1.03
1908–12	175.1	164.2	1.06

Source: Takekozu Ogura [31], p. 24.

The economic factors for the expansion of the rice area and the adoption of yield-improving technology were favorable throughout the first epoch, so that, as shown in Tables III.4 and III.5, real rice prices rose. By 1900 rice exports, which had risen continuously since the early 1870's, started to decline. Demand was increasing more rapidly than supply. The Japanese government's response was to undertake an intensive program to expand rice production in the northern island of Hokkaido and in the 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 was rather successful and rapid. Table III.6 shows that by the early 1920's approximately two-thirds of the rice area in Korea was planted to Japanese varieties.

[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, 435–78].

TABLE III. 5

Price Indexes for Rice and Wholesale Price Index in Japan: 1911–40
(1934–36 = 100)

	Wholesale Price Index *(G)*	Rice Price (1)		Rice Price (2)	
		Index (R_1)	Ratio (R_1/G)	Index (R_2)	Ratio (R_2/G)
Year					
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* (1)*: Japan Statistical Yearbook,* 1949, p. 634 – index base has been shifted from 1900 = 100 to 1934-36 = 100; *Rice Price* (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	Area (thousand hectares)	Per Cent of Total Rice Area	Average Yield of Brown Rice (kg./ha.)
Plantings of Japanese-Type Varieties			
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			
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

Source: Takekazu Ogura[31], p. 190; *Japan Statistical Yearbook*, Tokyo, 1949, pp. 630, 631; *Taiwan Food Statistics*, Taiwan Provincial Food Bureau, 1965 (and earlier issues), Taipei, pp. 18-22.

[a] The first crop in Taiwan is the dry-season crop.

However, as seen in Table III.7, rice yields in Korea did not increase significantly until at least the mid-1920's.

In Taiwan the direct transfer of Japanese varieties was not successful. Japanese rice varieties were not adapted to the Taiwan ecology.

TABLE III.7

Production, Area, and Yield of Brown Rice in Korea: 1912–40

	Production (thous. metric tons)	Area (hectares)	Yield (kg./ha.)
Year			
1912–13	1,630	1,405	1,160
1913–14	1,816	1,445	1,257
1914–15	2,120	1,472	1,440
1915–16	1,927	1,485	1,297
1916–17	2,090	1,506	1,387
1917–18	2,053	1,516	1,354
1918–19	2,294	1,535	1,494
1919–20	1,906	1,525	1,250
1920–21	2,232	1,543	1,447
1921–22	2,149	1,519	1,415
1922–23	2,252	1,545	1,458
1923–24	2.276	1,538	1,480
1924–25	1,983	1,563	1,269
1925–26	2,215	1,572	1,410
1926–27	2,295	1,575	1,457
1927–28	2,595	1,589	1,633
1928–29	2,027	1,505	1,346
1929–30	2,055	1,619	1,270
1930–31	2,877	1,648	1,746
1931–32	2,381	1,661	1,434
1932–33	2,452	1,630	1,504
1933–34	2,729	1,783	1,531
1934–35	2,508	1,698	1,477
1935–36	2,683	1,681	1,596
1936–37	2,912	1,588	1,833
1937–38	4,020	1,626	2,473
1938–39	3,621	1,646	2,200
1939–40	2,153	1,225	1,758
Average			
1912–13 to 1919–20	1,980	1,486	1,330
1920–21 to 1929–30	2,208	1,557	1,418
1930–31 to 1939–40	2,833	1,618	1,755

Source: *Japan Statistical Yearbook*, Tokyo, 1949, pp. 630, 631.

TABLE III.8

Production, Area, and Yield of Brown Rice in Taiwan: 1900–40

	Production (thous. metric tons)	Area (hectares)	Yield (kg./ha.)
Year			
1900–01	307	326	943
1901–02	438	353	1,239
1902–03	403	345	1,168
1903–04	525	395	1,330
1904–05	594	435	1,366
1905–06	622	447	1,390
1906–07	567	459	1,236
1907–08	645	472	1,367
1908–09	665	479	1,389
1909–10	661	479	1,381
1910–11	598	456	1,311
1911–12	642	479	1,340
1912–13	578	481	1,201
1913–14	732	498	1,482
1914–15	658	500	1,317
1915–16	684	491	1,392
1916–17	664	472	1,408
1917–18	691	466	1,481
1918–19	662	483	1,369
1919–20	703	497	1,415
1920–21	692	500	1,383
1921–22	711	495	1,435
1922–23	778	511	1,521
1923–24	695	508	1,369
1924–25	668	531	1,633
1925–26	920	551	1,671
1926–27	888	567	1,565
1927–28	985	585	1,685
1928–29	971	585	1,660
1929–30	926	568	1,630
1930–31	1,053	614	1,714
1931–32	1,069	634	1,686
1932–33	1,278	664	1,924
1933–34	1,195	675	1,768
1934–35	1,298	667	1,947
1935–36	1,303	679	1,920
1936–37	1,366	681	2,004
1937–38	1,319	658	2,006
1938–39	1,402	625	2,242
1939–40	1,307	626	2,088

(continued)

TABLE III.8 (concluded)

	Production (thous. metric tons)	Area (hectares)	Yield (kg./ha.)
Average			
1900–10 to 1909–10	543	419	1,281
1910–11 to 1919–20	661	482	1,372
1920–21 to 1929–30	823	540	1,555
1930–31 to 1939–40	1,259	652	1,930

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

Furthermore, the official economic policy of the Japanese administration in Taiwan 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 thirty 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

[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* 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.9). Japanese rice imports rose from an average of 559 metric tons, 6.4 per cent of total Japanese supply, in 1912–20, to 1,754 metric tons, 15.6 per cent of total supply, in 1931–40. During this latter period, imports from Korea accounted for 9.6 per cent and from Taiwan 5.5 per cent of the total Japanese rice supply.

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

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. As shown in Table III.12, 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.

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 thirty years prior to World War I, rice prices had risen steadily relative to the gen-

yields. Beginning in 1930 other *ponlai* varieties with greater resistance to the rice blast disease were introduced. Over twenty 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. 331–33].

TABLE III.9

Japanese Rice Production and Imports from Korea and Taiwan: 1912–61

	Domestic Production		Total Net Imports		Net Imports From Korea		Net Imports From Taiwan		Total Supply[a]
	Thous. metric tons	Per cent of total supply	Thous. metric tons	Per cent of total supply	Thous. metric tons	Per cent of total supply	Thous. metric tons	Per cent of total supply	Thous. metric tons
Year									
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

Year

1931	10,031	87.5	1,4[illegible]	12.5	1,194	10.4	[illegible]	[illegible]	11,460

1930	8,934	88.1	1,207	11.9	763	7.5	327	3.2	10,140
Year									
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
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									
1912–20	8,228	93.6	559	6.4	201	2.3	122	1.4	8,787
1921–30	8,834	87.7	1,241	12.3	668	6.6	264	2.6	10,075
1931–40	9,467	84.4	1,754	15.6	1,073	9.6	620	5.5	11,221

Source: *Japan Statistical Yearbook*, Bureau of Statistics, 1949, pp. 614, 615. Data converted from koku to metric tons at 150 kg. per koku.

[a]Supply equals production plus net imports.

TABLE III.10

Rice Supplies, Trade, and Domestic Utilization in Taiwan: 1910–11 to 1939–40

(thousands of metric tons)

	Supply			Domestic Utili- zation	Exports	Exports as Per Cent of Production
	Pro- duction	Imports	Total			
Year[a]						
1910–11	641	13	654	560	94	15
1911–12	578	18	596	503	93	16
1912–13	732	30	762	601	161	22
1913–14	658	11	669	583	86	13
1914–15	684	9	693	567	126	18
1915–16	664	11	675	564	111	17
1916–17	691	17	708	591	117	17
1917–18	662	48	710	559	156	23
1918–19	703	57	760	591	169	24
1919–20	692	27	719	615	104	15
1920–21	711	21	732	586	146	21
1921–22	778	47	825	718	107	14
1922–23	695	15	710	531	179	26
1923–24	868	18	886	624	262	30
1924–25	920	117	1,037	682	355	39
1925–26	888	67	955	643	312	35
1926–27	985	129	1,115	742	373	38
1927–28	971	46	1,017	678	339	35
1928–29	926	92	1,018	687	331	36
1929–30	1,053	14	1,067	750	317	30
1930–31	1,069	2	1,071	691	380	36
1931–32	1,278	37	1,315	838	477	37
1932–33	1,195	8	1,203	613	590	49
1933–34	1,298	1	1,299	578	721	56
1934–35	1,303	1	1,304	662	642	49
1935–36	1,365	1	1,366	683	683	50
1936–37	1,319	1	1,320	628	692	52
1937–38	1,402	2	1,404	708	696	50
1938–39	1,307	1	1,308	722	586	45
1939–40	1,129	13	1,142	719	423	37
Average						
1910–11 to 1919–20	671	24	695	573	122	18
1920–21 to 1929–30	880	57	937	664	273	31
1930–31 to 1939–40	1,267	7	1,274	684	590	47

Notes to Table III.10

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

[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.

eral price level, and Tables III.4 and Tables III.5 indicate that rice prices rose to their highest relative level in 1913 and their highest absolute level in 1919. The wholesale price of rice in Tokyo more than doubled between 1913 and 1919, and there were consumer riots during the very sharp price rise of 1916–19. As a response to the riots, official policies were designed to encourage rice production in and imports from the colonial areas.

Japanese imports increased sharply in the mid-1920's and remained above 1.2 million metric tons until after 1940 (Table III.12). From 1921 to 1940, the price of rice did not resume its upward drift relative to the general price level but 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 the period 1932–38 and reached their pre-World War II peak of 2.2 million metric tons in 1938.

The impact of rice imports from Taiwan and Korea on rice production, consumption, and prices in Japan during the interwar period 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 data on markets 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 reviews 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].

TABLE III.11

Korean Rice Production and Exports to Japan: Annual Averages 1912–16, 1917–21, 1922–26
(thousands of metric tons)

Years	Production	Exports	Exports as of Production
1912–16	1,771	152	8.5
1917–21	2,030	316	15.6
1922–26	2,088	625	29.9

Source: Ki Zum Zo [48], p. 315.

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 and 1940.

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.

Notes to Table III.12

Source: Japan—*Hundred YearStatistics of the Japanese Economy, Tokyo,* 1966. 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, Seoul, 1936 and 1940.

[a] 1912–19.

[b] 1930–36.

[c] 1936–38.

TABLE III.12

Per Capita Annual Consumption of Rice in Japan, Taiwan and Korea: 1910–40
(Kilograms)

	Japan	Taiwan	Korea (old series)	Korea (new series)
Year				
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				
1910–19	161.3	–	107.2[a]	
1920–29	168.4	166.5	86.3	
1930–39	162.4	133.1	64.0[b]	102.4[c]

TABLE III.13

Actual and Estimated Prices of Rice in Japan: 1921–40

(production, import, and supply figures in thousands of metric tons)

	Actual Data			Partial Isolation		
	Production	Imports	Supply	Price index[a]	Imports	Supply
Year						
1921	9,481	671	10,152	83	559	10,040
1922	8,277	1,024	9,301	97	559	8,835
1923	9,104	825	9,929	88	559	9,663
1924	8,317	1,313	9,630	100	559	8,876
1925	8,575	1,525	10,100	111	559	9,134
1926	8,955	1,348	10,303	113	559	9,515
1927	8,339	1,706	10,045	112	559	8,898
1928	9,316	1,537	10,853	97	559	9,874
1929	9,045	1,253	10,298	94	559	9,604
1930	8,933	1,207	10,140	72	559	9,493
1931	10,031	1,429	11,460	86	559	10,590
1932	8,282	1,639	9,921	89	559	8,841
1933	9,058	1,819	10,877	78	559	9,617
1934	10,625	1,997	12,622	93	559	11,183
1935	7,776	1,833	9,609	104	559	8,335
1936	8,619	2,047	10,666	103	559	9,177
1937	10,101	1,685	11,786	89	559	10,660
1938	9,948	2,203	12,151	90	559	10,507
1939	9,880	1,357	11,237	88	559	10,439
1940	10,345	1,533	11,878	92	559	10,904
Average						
1921–30	8,834	1,241	10,075	92	559	9,393
1931–40	9,467	1,754	11,221	97	559	10,025

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

[a] 1934–36 = 100.

[b] Equals supply.

Model I	Partial Isolation Model II				Isolation Model	
Price index[a]	Production	Imports	Supply	Price index[a]	Production[b]	Price index[a]
88	9,559	559	10,118	84	9,951	91
121	8,598	559	9,157	105	8,983	114
100	9,289	559	9,848	92	9,679	99
139	8,832	559	9,391	112	9,214	122
164	9,250	559	9,809	129	9,612	138
156	9,495	559	10,054	127	9,879	136
176	9,113	559	9,672	133	9,490	143
140	9,983	559	10,542	111	10,364	119
125	9,522	559	10,081	104	9,906	112
95	9,379	559	9,938	79	9,764	85
118	10,628	559	11,187	96	11,012	103
137	9,012	559	9,571	105	9,390	113
123	9,909	559	10,468	93	10,287	99
146	11,600	559	12,159	110	11,978	117
173	8,629	559	9,188	127	9,002	137
175	9,614	559	10,173	127	9,988	136
131	10,869	559	11,428	103	11,250	109
150	11,052	559	11,611	110	11,428	117
119	10,429	559	10,988	98	10,813	105
129	11,013	559	11,572	104	11,395	111
130	9,302	559	9,358	108	9,684	116
140	10,276	559	10,332	107	10,654	115

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 it actually was in the period 1921 to 1940 (implying 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 −0.20. Under these conditions rice prices would have risen to an average index of 140 for the 1931–40 period, 44 per cent 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 +0.50, (2) imports are held at the 1912–20 average level, and (3) the price elasticity of demand is assumed to be −0.20. It differs from 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, 10 per cent 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 period from 1921 to 1940, (2) the price elasticity of demand is assumed to be −0.20, and (3) the price elasticity of supply is assumed to be +0.50. Under these conditions the average 1931–40 price index would be 115. This is 19 per cent 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

[30] The actual average rate of rice production growth in the period between 1900–03 and 1919–22 was 1.3 per cent per year. The "isolation model" suggests a similar growth rate of 1.3 per cent for the 1919–22 to 1937–40 period when imports were presumed to be prohibited. The actual production growth rate was 1.1 per cent 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].

rice production in metropolitan Japan during the period 1920–40.[31] However, the data and analysis presented in this paper are 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 of the terms of trade to favor rice producers by turning it to favor 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. 419–42].

The transfer of rice-production technology from Japan to Taiwan and Korea and the Japanese policy on imports from these two countries during the period 1920–40 have 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 disruptions of trade and price relationships are anticipated in the absence of an effective international stabilization scheme.

IV. SUMMARY

We recognize that it is difficult to draw broad inferences about future patterns of international generation and transmission of technology in

[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.

agricultural products from the evidence in these three cases. However, we will summarize the common elements that we see in them. 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 more advanced the basic technology, the more highly organized the effort. Early sugarcane breeding, for example, was sometimes accomplished on individual plantations. Virtually all 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. Similarly, advances in rice breeding were and are being produced by experiment stations established for this purpose, and 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 improved methods in that area. The history of sugarcane breeding reveals many instances in which a disease problem was 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 technological characteristics that appear to be most important are the sorts of information or knowledge required to insert the technology into the actual production processes. The simplest 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

[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.

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, thus Stage-II sugarcane varieties were transferred relatively easily.

But the transmission of technology becomes more difficult as more information is required. For example, the Stage-III sugarcane varieties were not easily transferred because specific information was needed about the diseases to which each of the new varieties was resistant. (A similar amount of information was required on the banana diseases.) Rapid transmission of technology based on this degree of information took place only through 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. So that, in addition to organized research effort, some form of extension effort often is required to achieve transmission of new technology. In the banana case, the solution to the processing and marketing problems took the form of an important new technical advance. The transmission of rice varieties from Japan to Korea involved knowledge of new cultural practices.

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 and requires a minimum number of competent research scientists committed to the transfer and further development of the technology. In addition, the organization must provide the environment for the communication and complementary interchange of knowledge by scientists within the nation and internationally.

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 confirm this expectation.

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 with limited research activity. In a few additional cases, such as the spread of open-pollinated corn in Thailand, the transfer has involved some extensive 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 efforts in other tropical crops are also exceptions.

The technology gap for many of the major feeds and food grains exists largely because good Stage-IV research organizations do not exist yet in many less-developed countries. This gap has been widened as the research organizations of the developed countries have continuously generated new technology and technical change which have 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, however, the Ford and Rockefeller Foundations have partially succeeded.[33] The Rockefeller program in Mexico and the

[33] The economic development efforts associated with the foreign aid and

International Rice Research Institute (IRRI) in the Philippines are examples of the kinds of research organizations which are essential if the technology gap is to be closed.

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. We would expect this research activity effort to result in a narrowing of the present technology gap and to stimulate a "catching-up" phase by the less-developed economies.[34]

World trade and individual country gains from trade are, or course, both influenced by this catching-up phase. It is difficult to speculate in detail about the specific shifts in trade, but evidence from the three cases in this paper clearly indicates that shifts in technology levels do affect trade patterns. We expect that the less-developed countries, for example, will become more self-sufficient in the production of certain feed and food grains, and that 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 reexamined as many of the developing countries expand their own food production with newly developed technologies.

This catching-up phase due to the international transmission of technology generally should result in an improvement in the welfare position of the less-developed countries as they become more competitive in world markets. Those developed countries which are presently exporters enjoying a long lead in technology will probably experience a decline in their competitive position. We do not see serious over-all welfare considerations arising from this change since it represents improvement

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.

[34] This development of an international technology gap followed by its later reduction is not peculiar to agricultural products [30].

in the welfare of poorer nations relative to rich nations. Nevertheless, the pressure from producers in the developed countries for protectionist trade policies to maintain present trade patterns and price levels will probably be intensified.

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COMMENT

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The paper by Evenson, Houck, and Ruttan is a valuable contribution to our understanding of the forces influencing the success of the generation and international transfer of agricultural techniques. When President Truman announced the Point Four of his 1949 Inaugural Address, the view was widely shared in America that we possessed a cheap "technological fix" for the problems of poverty and backwardness which beset most of the human race. We are, most of us, sadder and wiser today. Of course opportunities exist for raising agricultural productivity by the transfer of existing technology, but most of the very high payoffs may very well have been exhausted. This paper, by focusing on the historical experience of three major crops, provides important insights into the opportunities and the constraints which confront policymakers.

Several factors stand out. First of all, the transfer of agricultural techniques presents certain special difficulties because agricultural activity is always immersed, as manufacturing is not, in a unique ecological environment. The success of an individual crop will often depend on a single quality or a delicate combination of qualities of the natural environment—topography, rainfall, sunlight, chemical composition of soil, temperature variations. Therefore, each region and often each subregion will have to develop, through on-the-spot research, optimal adaptations to local ecological characteristics—as in the breeding of disease-resistant, higher-yielding seed varieties. In most cases the transfer of technology will therefore have to involve not specific tangible inputs, such as a plant seed, but a knowledge of certain scientific principles and techniques, such as genetics, biochemistry, and plant-breeding techniques.

For most of the major crops, large-scale improvements in productivity are going to be dependent on organizations capable of engaging in research of a high scientific quality. In fact, one of the interesting findings of this paper is that, in the case of the three crops, the research efforts had to become more highly organized in an institutional sense as the basic technology became more advanced. The authors conclude that the highest payoff to American technical assistance programs overseas may well be in the establishment of first-rate research organizations.

The discussion of the Japanese effort to raise Taiwan rice yields is very illuminating in this regard. The direct transfer of Japanese techniques failed due to ecological differences between Japan and Taiwan. Success came only after Japanese technical skill was used to breed rice varieties which conformed to the requirement of Taiwanese ecology. It is worth noting that this transfer, which was eventually highly successful, took fully twenty years to accomplish. It is also worth noting, if only in passing, that agriculture's close involvement with nature has another consequence which is significant in inhibiting acceptance of new techniques: because of the importance of even minor variations in rainfall, diurnal rhythms, soil content, etc., there is an unusually high degree of uncertainty concerning the outcome of untried agricultural techniques.

This paper makes it clear that the common practice of treating production functions, involving similar inputs as identical and therefore available to all—much as the information in a cookbook—is not a reasonable characterization of the situation in world agriculture. Abstract bodies of scientific knowledge, such as one finds in biology and genetics, are in some sense available, but these bodies are not capable of direct and easy translations into practical technical applications. One result is that in the case of agriculture what we are calling the *transfer* of technology demands a very high order of talent and scientific training to carry it out successfully—so high, in fact, that one is led to question whether the terminology itself may not be misleading. This paper suggests to me that what we are calling "transfer" (or "diffusion") often involves activities which are very difficult to distinguish, in any meaningful way, from what we ordinarily call "innovation."

A further point which is suggested by a reading of this paper, which the authors do not stress, is the extreme importance of complementarities. First, in order to apply fertilizers successfully to rice crops in southeast

Asia, it has been necessary to breed new rice varieties possessing the appropriate genetic capacities, and, second, the success of the new-varieties-cum-fertilizer approach to higher rice yields has been heavily dependent upon appropriate measures of water control. In addition, the high cost of the required irrigation systems suggests that the gains resulting from new varieties may not come as cheaply as had once been expected. In any case, the whole subject of the exact nature of the complementarities (including regional variations) between (1) new seeds, (2) fertilizer inputs, (3) irrigation systems, and (4) other infrastructure requirements, such as drainage, would seem to be one worthy of a very high research priority. Indeed, it is difficult to see how intelligent allocation decisions can be made in the absence of much more detailed quantitative information than we now have concerning the response of output to the whole range of possible input combinations.

This paper impresses me with the importance of complementarities in a somewhat broader sense. It seems clear that the productivity of a country's agricultural sector will frequently depend not only on resources within that industry, but on the availability and the effectiveness of industries which stand in an important complementary relationship with it. The growing role of a changing technology suggests the increasing importance of the development of new technological inputs (including pure knowledge) by industries outside the agricultural sector. Certainly in the American experience the growth in agricultural productivity was heavily dependent on the machinery sector which developed a whole new mechanical technology appropriate to our special factor endowment, as well as upon the fertilizer industry and upon new educational institutions devoted to the study of such subjects as soil chemistry and genetics. Rapidly changing technology makes it increasingly important that we think in terms of such complementarities instead of in the more static terms of resource endowment and comparative advantage.