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SOURCES OF AGRICULTURAL GROWTH IN JAPAN, 1880-1965

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Throughout the process of modern economic growth in Japan, especially in its early phase, agriculture supported the development of the nonagriculture sector by meeting the food and raw materials requirements of a rapidly expanding economy and sometimes transferring labor and capital to the nonagricultural sector. This experience of Japan has frequently been identified as a typical example of the role of agriculture in economic development.[1)] Failure to achieve rapid growth in agricultural output and productivity would have seriously impeded the growth in industrial production, as in many presently developing countries. It is thus critical for the understanding of the overall economic development process to identify the causes of agricultural growth. Yet, as measured by the total productivity of the Kendrick type, more than half of the long-term growth in agricultural output in Japan since the early Meiji period (1880-1965) is left unexplained by the conventional inputs including labor, land, capital, and current inputs such as fertilizer.

In this study we attempt to reduce our ignorance on the sources of agricultural growth by narrowing the gap between the growth in real output and in the aggregate of real factor inputs in agriculture. For this purpose we employ the technique of growth accounting developed by Zvi Griliches[2)]: (a) to identify the education of farmers and the activities of agricultural research and extension as factors of agricultural production, and (b) to use as the weights of aggregating inputs the production elasticities obtained from the cross-sectional estimates of the aggregate agricultural production function. Although the Griliches approach has now been accepted as a standard technique of growth accounting, our study represents the first attempt to apply the technique to the accounting of long-term growth, encompassing the period of nearly a century.

Our analysis indicates that our attempt is successful in reducing the unexplained portion of secular growth in agricultural output. It also indicates that significant residuals remain for the different phases of agricultural development in a way consistent with the previously postulated hypothesis on the time lag between the accumulation and the diffusion of scientific knowledge and technology.[3)]

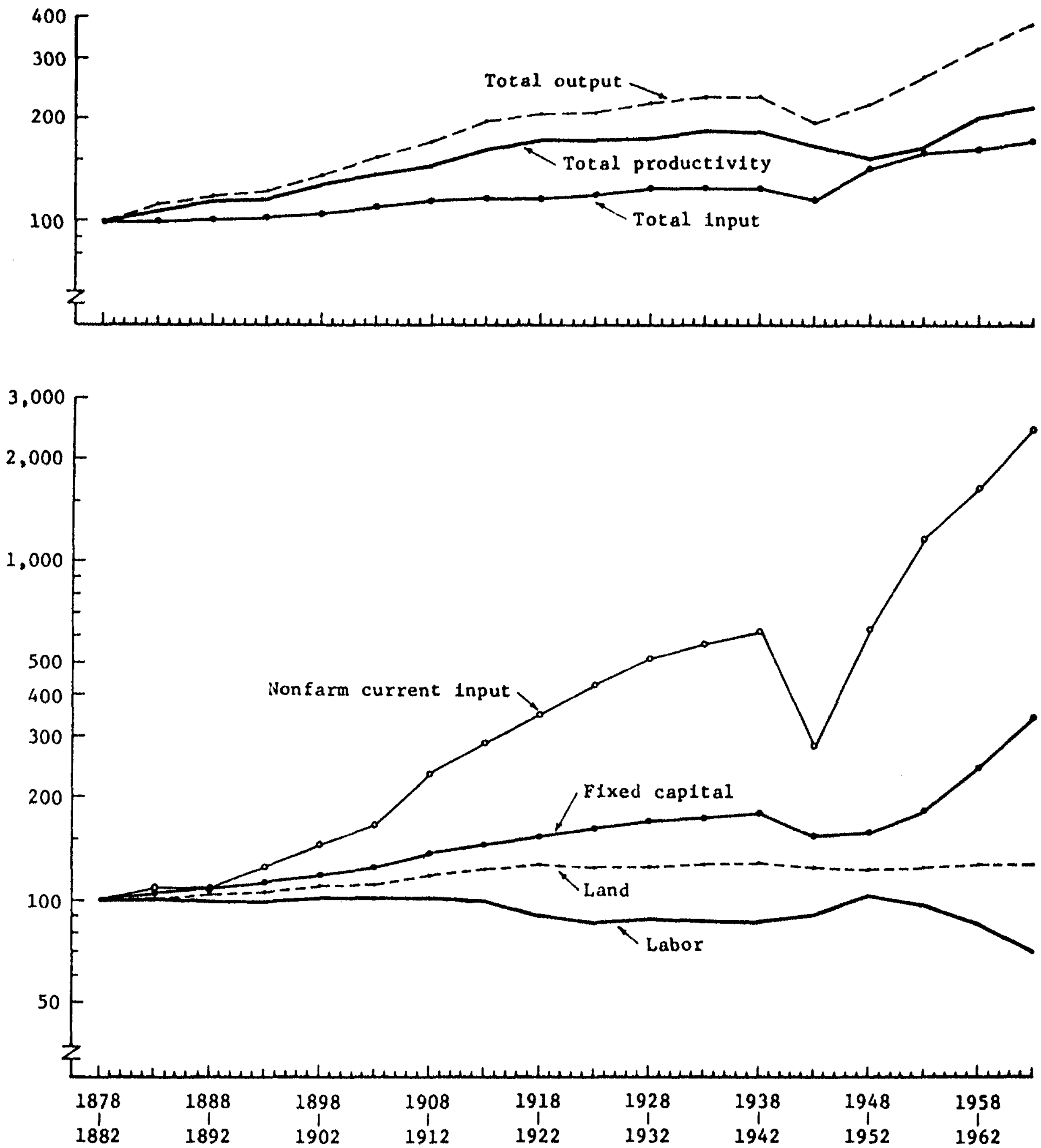
I. OUTPUT, INPUT, AND PRODUCTIVITY[4)]

Before proceeding to the growth accounting analysis we will review the trends in agricultural output, inputs, and productivity in Japan for 1880-1965. Those trends are represented by the indices show in Figure I.

The total output (Y) used here for the measurement of growth rates in agricultural output is the aggregate of all individual agricultural products valued in 1934-36 average prices, after deducting the intermediate products for agricultural production, such as seeds and feed. Labor (L) is measured in terms of the number of gainful workers in agriculture; female workers are converted into male equivalents by the male/female wage ratio. Land (A) is in terms of arable land area; upland fields are converted into paddy field equivalents by the land price ration. Fixed capital (K) is the aggregate in 1934-36 prices, which is gross of depreciation. Nonfarm current inputs (C) are the current

Figure I

TRENDS IN THE INDICES OF OUTPUT, INPUTS, AND PRODUCTIVITY IN AGRICULTURE (1878-82=100), FIVE YEARS' AVERAGES, SEMI-LOG SCALE.



Source: Saburo Yamada and Yujiro Hayami, Growth Rates of Japanese Agriculture, 1880-1965. Paper presented at the conference on Agricultural Growth in Japan, Korea, Taiwan, and the Philippines, sponsored by the University of Hawaii East-West Center Food Institute and the University of Minnesota Economic Development Center, held at Honolulu, Hawaii, February 6-9, 1973.

inputs in agriculture supplied from the nonfarm sector, such as fertilizers and agricultural chemicals, aggregated by the 1934-36 prices.

The indices of those four input categories are aggregated into the total input index (X) by factor share weights, based on the Divisia index formula. The total output index divided by the total input index (Y/X) produces the total productivity index.

The rates of growth in total output and the relative contributions of changes in inputs and productivity to the output growth rates are calculated in Table I.

<u>Long-term trends</u>

For the period 1880-1965 total output, input, and productivity in Japanese agriculture show secular growth trends, except for the period of devastation due to World War II. Over the whole period the total output more than tripled. Inputs of the two primary factors, labor and land, changed relatively slowly; labor declined by less than 20 per cent throughout the prewar period and by another 20 percent within a decade from 1955 to 1965 under extremely rapid economic growth; and land increased only by 30 percent in the whole period. To a large extent the changes in labor and land have cancelled each other in the growth in total input. Capital grew relatively slowly during the prewar years, but rose rapidly during the postwar period. The rates of growth in current nonfarm inputs, particularly fertilizers, have been much faster than in other inputs.

Overall, total input grew for the whole period (excluding the years of war devastation) at the annual compound growth rate of 0.5

TABLE I

ACCOUNTING FOR THE GROWTH IN AGRICULTURAL OUTPUT, BASED ON FACTOR SHARE WEIGHTS, IN TERMS OF ANNUAL COMPOUND RATES OF GROWTH (%)

			Contributions to output growth rates of					
			Conventional inputs					
		Output $(\dot{Y}/Y)$	Labor $\delta_L(\dot{L}/L)$	Capital $\delta_K(\dot{K}/K)$	Current Inputs $\delta_F(\dot{F}/F)$	Land $\delta_A(\dot{A}/A)$	Total Input $(\dot{X}/X)$	Residual: Total Productivity $(\dot{Y}/Y) - (\dot{X}/X)$
Prewar period:	1880-1935	1.6 (100)	-0.14 (-9)	0.11 (7)	0.32 (20)	0.14 (9)	0.43 (27)	1.17 (73)
Phase 1:	1880-1920	1.8 (100)	-0.15 (-8)	0.11 (6)	0.30 (17)	0.18 (10)	0.44 (25)	1.36 (75)
I.	1880-1900	1.6 (100)	0 (0)	0.09 (6)	0.14 (9)	0.16 (10)	0.39 (25)	1.21 (75)
II.	1900-1920	2.0 (100)	-0.30 (-15)	0.13 (7)	0.47 (23)	0.21 (11)	0.51 (26)	1.49 (74)
Phase 2:	1920-1935	0.9 (100)	-0.10 (-11)	0.10 (11)	0.38 (42)	0.03 (3)	0.41 (45)	0.49 (55)
Postwar period:	1955-1965	3.6 (100)	-1.53 (-43)	0.76 (21)	1.29 (36)	0.02 (1)	0.54 (15)	3.06 (85)
Whole period:	1880-1935 and 1955-1965	1.9 (100)	-0.35 (-18)	0.21 (11)	0.47 (25)	0.13 (7)	0.46 (25)	1.44 (75)

Source: Factor shares (δ's) from Table IV. The growth rates of output and inputs from the same source as for Figure I.

Inside of parentheses are percentages with the growth rate of output set equal to 100.

per cent, while the total output grew at 1.9 per cent. Consequently, the total productivity more than doubled at the growth rate of nearly 1.4 per cent per year. This implies that about three-quarters of the growth in agricultural output is left unexplained by the growth in inputs. More or less the same conclusion is derived when we limit our analysis to the prewar period.

Phases of growth

In terms of total output and productivity three major phases are distinguished: (a) relatively fast growth up to the late 1910's, (b) relative stagnation in the interwar period, and (c) renewal of rapid growth in the post World War II period (Table I). It appears that during the initial growth phase (Phase 1) the growth rates of both output and productivity accelerated at the beginning of this century. Subsequently, Phase 1 is divided into two sub-periods: I (1880-1900) and II (1900-1920).

There are large variations among phases in the rate of growth in total productivity as well as in its relative contribution to the output growth rate. The increase in the rate of output growth from sub-period I to sub-period II in Phase 1 is associated in both with the rise in the input growth rate and in the acceleration in productivity growth. Throughout Phase 1 the productivity growth is the dominant factor in determining the growth rate of agricultural output. More conspicuous is the fact that the stagnation in the output rate in Phase 2 is solely explained by the deceleration in the rate of growth in productivity.

From the prewar to the postwar periods the growth rates of total output and input increased significantly. However, the acceleration in the former outpaced the latter, resulting in the decline in the relative contribution of factor inputs to the growth in output for the postwar period.

From the above observations it should be clear that the aggregate of four conventional inputs—labor, land, capital, and current inputs—based on factor share weights, are grossly insufficient not only for explaining the long-term secular growth in agricultural output but also for explaining changes in the output growth rate among the different phases of agricultural development in Japan.

The apparent failure in accounting for agricultural output growth by the conventional total input index led us to explore the approach reported in the subsequent sections.

II. METHOD AND DATA

The approach used in this study involved the estimation of the aggregate agricultural production function on the basis of 46 cross-prefectural data. Using the production elasticities from the estimates of the production function as weights for aggregation, the growth in agricultural output is accounted for by changes in four conventional inputs—land, labor, capital, and current inputs—and in two non-conventional inputs—farmers' education and agricultural research and extension.

Production functions were estimated for two pre-World War II periods, 1930 (1928-32 averages) and 1935 (1933-37 averages); and for two postwar periods, 1960 (1958-62 averages) and 1965 (1963-67 averages). Growth accounting was conducted for pre and postwar periods separately, using the different estimates of the production elasticities.

Specification of production function

In the growth accounting approach it has been customary to employ the production function of the Cobb-Douglas or log-linear form, primarily for its ease in manipulation. It has been argued that the constant production elasticities implied in the Cobb-Douglas production function is not a critical limitation for the short to the medium range analysis.[5)] In this study, also, we have adopted the Cobb-Douglas production function for the growth accounting of the postwar period, 1955 to 1965.

However, the constancy of production elasticities is clearly not a sufficient approximation for the analysis of long-term growth in the prewar period, which extends over a half century involving major technical changes. The constant elasticities cause no problem if we can estimate them for different technical epochs, but sufficient cross-prefectural data for the estimation of the aggregate agricultural production function are unavailable before the 1930 time point.

It is especially difficult to assume the constancy of the elasticities of land and current inputs (of which fertilizer was the dominant factor). In agriculture in prewar Japan, because land was relatively scarce and labor was relatively abundant, efforts for technical improvements were concentrated on saving land or increasing the output per unit of limited land area, primarily through the development of fertilizer-responsive high-yielding varieties and related cultural practices. This implies innovations facilitating the substitution of fertilizer and other current inputs, such as pesticides, for arable land.[6] Such bias in technical change is also reflected in the decrease in the share of land and the corresponding increase in the share of current inputs in the total cost of agricultural production, especially before 1920.[7]

Another critical aspect should be the constancy of the production elasticity for research and extension. T.W. Schultz has argued that agricultural research is characterized by scale economies.[8] The Schultz hypothesis has been supported empirically by Robert Evenson.[9] Between 1880 and 1930 Japan established a modern system of agricultural research and extension. Public expenditure for research and extension rose more than 20 times during this period.[10] Given the scale economies of the technology-producing sector, especially in its infant stage, it it highly unlikely that the production elasticity of research and extension remained constant for the prewar 60 years.

For those considerations we estimated not only the ordinary Cobb-Douglas production function but also its modified form, in that the coefficients of land, fertilizer, and research and extension vary in correspondence with changes in their levels. While the ordinary Cobb-Douglas function in logarithmic transformation is specified as

$$(1) \quad \log(Y/A)_i = \alpha_0 + \alpha_L \log(L/A)_i + \alpha_K \log(K/A)_i + \alpha_F \log(F/A)_i + \alpha_E \log E_i + \alpha_R \log R_i + \sum_{j=0}^{5} \delta_j D_j + U_i$$

the modified form is

$$(2)\quad \log(Y/A)_i = \alpha_0 + \alpha_L \log(L/A)_i + \alpha_K \log(K/A)_i + \beta_F\sqrt{(F/A)_i} + \alpha_E \log E_i + \beta_R\sqrt{R_i} + \sum_{j=0}^{5} \delta_j D_j + U_i$$

Where

Y = output	E = education
A = land	R = research and extension
L = labor	D_j = regional dummy (j=0...5)
K = capital	U = error term
F = fertilizer	

and the subscript-i's denote prefectures.

In both equations (1) and (2) output and conventional inputs are expressed in per-unit-of-land terms, and the production elasticity of land (α_A) is obtained as one minus the sum of production elasticities of labor (α_L), of capital (α_K), and of fertilizer (α_F), assuming linear homogeneity ($\alpha_L + \alpha_K + \alpha_F + \alpha_A = 1$). While the coefficients of equation (1) are themselves the production elasticities, in equation (2) the production elasticities of fertilizer and of research and extension are derived as

$$\alpha_F = \frac{1}{2}\beta_F\sqrt{\frac{F}{A}} \qquad \text{and} \qquad \alpha_R = \frac{1}{2}\beta_R\sqrt{R}$$

In other words, the production elasticities of F and R in equation (2) are specified as the increasing functions (at decreasing rates) of (F/A) and R, respectively, for the positive values of β_F and β_R.

For the positive estimate of β_F the production elasticity of fertilizer (α_F) increases, and the implicit coefficient of land (α_L), which can be obtained from the linear homogeneity assumption, decreases in correspondence with the rise in the inputs of fertilizer per unit of arable land area. This specification is consistent with the pattern of land-saving and fertilizer-using technical progress in pre-war Japan. Also, the production elasticity of research and extension in equation (2) increases at a declining rate, consistent with the pattern expected in the period of rapid evolution from an infant stage to a mature stage of the national system of research and extension in agriculture.

The problem is whether such bias in technical progress in agriculture and scale economies in research investment over time were reflected in the cross-prefectural data in the 1930's. Of course, validity of the extrapolation of cross-sectional estimates into a time-series dimension is always open to question. However, it seems reasonable to expect that the cross-prefectural variations in the effects of scale economies of research and extension on agricultural production in Japan in the 1930's were sufficient to estimate the scale economies. Evenson successfully estimated scale economies for research and extension in the United States using inter-state cross-sectional data for the 1950's.[11)]

It appears even more reasonable to assume wide inter-regional variations in agricultural technology with respect to factor-saving bias. In this period northeastern districts (particularly Tohoku) were still agriculturally backward relative to southwestern districts (particularly Kinki and Northern Kyushu), though the inter-regional technology gap had been reduced since the early Meiji period.[12)] In 1930-35 the average fertilizer input per hectare of arable land in paddy field units in the Kinki district was about 100 per cent higher than in the Tohoku district. In the same period it is estimated that the difference in the price of fertilizer between Kinki and Tohoku was only 20 per cent at a maximum. Since the long-run price elasticity of demand for fertilizer was estimated as about unity,[13)] only 20 per cent of the difference in the input of fertilizer per hectare can be explained by the difference in prices. The remaining 80 per cent should be explained by the difference in the level of fertilizer-using technology. This evidence seems to support a presumption that the cross-prefectural data in the 1930's reflect, to a significant extent, differences in the fertilizer-using and land-saving technical progress over time.

Both equations (1) and (2), because the variables are expressed in per-land-unit terms, have a limitation in that it is not possible to test the economies of scale with respect to conventional inputs. This is to avoid the strong multi-collinearity between land and labor. This limitation does not seem critical for the prewar analysis, since micro production function estimates using farm survey data invariably indicate that constant returns prevailed before World War II and even until 1955.[14)] However, there is some sign that the scale economies have emerged in Japanese agriculture since the late 1950's with the development of mechanical technology, although the evidence is not conclusive.[15)] We do not deny a possibility that the specification of linear homogeneous production functions might have caused some bias in our growth accounting, especially for the postwar period.

A number of other specifications of the production function, including the CES type, were tried and the results are reported elsewhere.[16)] They do not seem to imply different conclusions from those presented here regarding the growth accounting analysis.

Data

Here we will explain briefly the cross-prefectural data for the variables included in the specified production function.[17)] In principle the data are five years' averages centering 1930, 1935, 1960, and 1965, respectively.

The output variable (Y) is in terms of gross agricultural output, measured in 1934-36 constant prices for the prewar period and in 1960 constant prices for the postwar period. The unusually bad crop years of 1929 and 1934, were excluded from averaging as they do not seem to reflect the "normal" production capacity.

Land (A) is measured in paddy field units which are equivalent to a chō (0.9917 hectare) of lowland paddy field; upland field areas are converted into areas in paddy field units by applying the ratio of the price of upland field to the price of lowland paddy field.

Labor (L) is in terms of number of male worker units: the sum of the numbers of gainful male workers and of female workers converted into male units by applying the ratio of male wage rate to female wage rate.

Fertilizer (F) for the prewar period represents the purchased current inputs in agriculture measured in terms of 1934-36 constant prices. For the postwar period the aggregates of farm expenditures for current inputs, including fertilizer, pesticides, insecticides, and others are adopted as the series for F.

As the capital variable (K), we adopted for the prewar period the stock of livestock capital as representing the total capital stock in agriculture. For the postwar period we took the stock of farm machinery and implements as representing farm capital in the 1960's.

The education variable (E) is measured in terms of average schooling years of farm workers.

The variable for research and extension (R) is the accumulation of annual expenditures for agricultural research and extension activities both by central and local governments for the past 15 years ending in the year of analysis divided by the number of farms in each prefecture. The annual expenditures are accumulated after being deflated by the consumer price index. For the prewar period the research and extension expenditures are measured independently for each prefecture. For the postwar period those expenditures are pooled and averaged among prefectures within each of 11 ecological regions. The data prepared in this way brought about better results for the postwar analysis.[18)] This appears to imply that the spill-over effects of research among prefectures in the same ecological region became dominant in the 1960's with the progress of communication systems.

Five regional dummy variables (D_j's) are adopted in order to adjust for the effects of differences in climate and other environmental conditions on agricultural production.

III. CROSS-PREFECTURAL PRODUCTION FUNCTION

The main results of estimation of the cross-prefectural agricultural production function, based on data for 46 prefectures, are summarized in

Table II

ESTIMATES OF AGRICULTURAL PRODUCTION FUNCTION ON CROSS-PREFECTURAL DATA, 1930 (1928-32 AVERAGES) AND 1935 (1933-37 AVERAGES)

Regression number		1	2	3	4	5	6	7
Year		1930	1930	1935	1935	1930-35	1930-35	1930-35
Sample Size		46	46	46	46	92	92	92
Labor	(logL/A)	.465 (.108)	.457 (.104)	.344 (.098)	.337 (.095)	.404 (.071)	.396 (.067)	.423 (.064)
Livestock capital	(logK/A)	.145 (.058)	.187 (.055)	.119 (.054)	.176 (.054)	.136 (.038)	.188 (.037)	.165 (.036)
Fertilizer	(logF/A)	.241 (.059)	.249 (.053)	.323 (.058)	.323 (.052)	.280 (.039)	.284 (.035)	
	($\sqrt{F/A}$)							.0357 (.0042)
Education	(logE)		.169 (.138)		.144 (.102)		.156 (.078)	.140 (.077)
Res. and ext.	(logR)		.210 (.069)		.138 (.054)		.167 (.040)	
	($\sqrt{R}$)							.0692 (.0183)
Regional dummies :								
D_1 (Hokkaido, Tohoku, Northern Kanto)		-.038 (.031)	-.052 (.028)	-.046 (.029)	-.048 (.027)	-.042 (.020)	-.049 (.018)	-.057 (.018)
D_2 (Southern Kanto, Hokuriku)		.017 (.036)	-.005 (.034)	.029 (.034)	.024 (.031)	.023 (.024)	.011 (.022)	.007 (.022)
D_3 (Tozan, Tokai)		-.007 (.036)	-.049 (.035)	-.021 (.034)	-.039 (.032)	-.014 (.024)	-.042 (.022)	-.052 (.022)
D_4 (Kinki)		.067 (.033)	.049 (.031)	.050 (.031)	.041 (.029)	.058 (.022)	.045 (.020)	.041 (.020)
D_5 (Chugoku, Shikoku)		-.010 (.027)	-.003 (.025)	-.010 (.026)	-.0002 (.024)	-.011 (.018)	-.002 (.016)	-.008 (.016)
Time Dummy : T_{35}						.014 (.011)	-.034 (.014)	-.029 (.014)
Constant term		1.489	1.231	1.589	1.308	1.531	1.282	1.480
Coef. of det. (adj.)		.819	.854	.828	.855	.835	.867	.869
S.E. of est.		.053	.048	.052	.047	.051	.045	.045
Implicit Coef. of land		.149	.107	.214	.164	.180	.132	.112

Equations are estimated by the least squares. The standard errors of coefficients are in parentheses.

Table III

ESTIMATES OF AGRICULTURAL PRODUCTION FUNCTION ON CROSS-PREFECTURAL DATA, 1960 (1958-62 AVERAGES) AND 1965 (1963-67 AVERAGES)

Regression number		8	9	10	11	12	13
Year		1960	1960	1965	1965	1960-65	1960-65
Sample Size		46	46	46	46	92	92
Labor	(logL/A)	.287	.292	.250	.294	.277	.285
		(.105)	(.106)	(.069)	(.059)	(.059)	(.060)
Machinery capital	(logK/A)	.284	.199	.357	.303	.305	.259
		(.113)	(.116)	(.079)	(.066)	(.064)	(.061)
Current Inputs	(logF/A)	.243	.224	.274	.218	.260	.226
		(.074)	(.078)	(.043)	(.040)	(.039)	(.038)
Education	(logE)		.236		.731		.508
			(.921)		(.552)		(.581)
Res. and ext.	(logR)		.046		.063		.055
			(.041)		(.050)		(.031)
Rogional Dummies :							
D_1 (Hokkaido, Tohoku, Northern Kanto)		.044	.040	.035	.033	.040	.038
		(.025)	(.024)	(.016)	(.014)	(.014)	(.013)
D_2 (Southern Kanto Hokuriku)		.025	.032	.036	.040	.030	.034
		(.030)	(.030)	(.017)	(.015)	(.016)	(.015)
D_3 (Tozan, Tokai)		.026	.035	.007	.013	.017	.019
		(.027)	(.028)	(.019)	(.016)	(.016)	(.014)
D_4 (Kinki)		.019	.032	.009	.016	.015	.021
		(.031)	(.031)	(.021)	(.018)	(.018)	(.017)
D_5 (Chugoku, Shikoku)		-.003	.020	-.013	.008	-.008	.012
		(.025)	(.026)	(.016)	(.014)	(.014)	(.014)
Time Dummy : T_{65}						-.037	-.032
						(.022)	(.020)
Constant term		1.486	1.401	1.234	1.203	1.371	1.323
Coef. of det.(adj.)		.771	.770	.899	.901	.870	.869
S.E. of est.		.044	.044	.031	.030	.037	.037
Implicit Coef. of land		.186	.285	.119	.185	.158	.230

Equations are estimated by the least squares. The standard errors of coefficients are in parentheses.

Tables II and III for the prewar and the postwar periods. Each column reports the results of a least squares regression of gross agricultural output per hectare of paddy-field-equivalent land area (in logarithm) on a different set of variables specified, including estimates of the production coefficients and their standard errors (in parentheses), the standard error of estimate (S.E.), and the coefficient of determination adjusted for the degree of freedom. Except Regression (7), which is the estimate of equation (2), they represent the estimates of the ordinary Cobb-Douglas production function.

Considering the crudeness of data, the levels of statistical significance of the estimated coefficients seem satisfactory in most cases, except for the coefficients of education in the postwar regressions. The coefficients stay fairly stable when nonconventional variables are added or subtracted. Comparisons of the estimates from the data of different time points and of the pooled data indicate the stability of the production function over time both within the prewar period and within the postwar period.[19]

In terms of the goodness of fit to data, as measured by the coefficient of determination, Regression (7) is slightly better than Regression (6). This may be taken as an evidence to support the specification of equation (2) for the prewar analysis.

<u>Comparison with factor shares</u>

Here we will examine the estimates of production elasticities in Tables II and III in comparison with the factor share estimates.[20]

Modal values of the estimates of production elasticities and the estimates of factor shares in the comparable periods are roughly as follows:

	Production elasticities	Factor Shares
Prewar (1930-35):		
Labor	0.4	0.5
Capital	0.15	0.1
Fertilizer	0.3	0.1
Land	0.15	0.3
Postwar (1960-65):		
Labor	0.3	0.5
Capital	0.3	0.1
Fertilizer	0.2	0.2
Land	0.2	0.2

A clear contrast exists between the 1930-35 and the 1960-65 periods in the way that the production elasticities differ from the factor shares. For the 1930-35 period the production elasticity of fertilizer is estimated to be much larger than the fertilizer's distributive share, and the production elasticity of land to be much smaller than the land's share. In contrast, for the 1960-65 period the production elasticities of capital and labor diverge significantly from their factor shares; production elasticities are larger for capital and smaller for labor, respectively, relative to their factor shares.

Differences between the 1930-35 and the 1960-65 periods, in the way that production elasticities diverge from the factor shares, seem to reflect the differences in the pattern of technical progress in agriculture in Japan between the prewar and the postwar periods. As previously explained, in the prewar period technical innovations were primarily motivated to overcome the constraint of land endowment on agricultural production, by developing such technologies as fertilizer-responsive high-yielding varieties, which facilitate the substitution of fertilizer and other current inputs for land. Those land-saving and fertilizer-using innovations were, to a large extent, induced by the rapid decline in the price of fertilizer relative to the price of land.[21)]

It appears reasonable to hypothesize that there had emerged disequilibria in the levels of inputs of fertilizer and land due to a lag in the adjustment of farmers to rapidly changing equilibrium levels corresponding to a rapid decline in the relative prices of fertilizer and land, and to the rapid progress in land-saving and fertilizer-using technology.[22)] This is consistent with Griliches' finding in his cross-regional analysis of the agricultural production function that the disequilibrium in the form of a gap between a production elasticity and a factor share existed also in the United States during a period that was also characterized by a rapid decline in the price of fertilizer.[23)]

In the postwar period the situation began to change drastically with the dramatic spurt in industrial development since the mid-1950's. The labor force in agriculture began to decline and the wage rates to rise rapidly, especially since 1960. Also, industry in Japan has increased its capacity to supply sophisticated farm machinery and implements to the agricultural sector. In response to rapid rises in the wage rates relative to the machinery prices the substitution of power and machinery for labor has become a major concern of farm producers. The primary motivation for innovations in agriculture began to shift from saving land to saving labor.

In such a situation it is reasonable to expect that disequilibria, as reflected in a gap between production elasticities and factor shares, have emerged with respect to labor and machinery capital due to a lag of farmers' adjustment to changes in technology and relative prices. It is entirely consistent to have disequilibria in the levels of inputs closely related with rapid technical changes — land and fertilizer in the prewar period, and labor and machinery capital in the postwar period.

Comparison with previous estimates

The results of our estimation may be checked with the earlier studies of the agricultural production function.

A classical study by Kazushi Ohkawa, based on production cost survey data for 1937-39 in the eastern part of Japan, resulted in the estimates of the elasticities of rice production as 0.2 to 0.3 for labor; 0.4 to 0.5 for land; and 0.3 for current inputs (which Ohkawa called "working capital").[24)] Ohkawa found those estimates consistent with the factor shares in rice production. Keizo Tsuchiya estimated the same model as Ohkawa, using production cost survey data from the Shizuoka prefecture, for 1951 when the prewar pattern of land scarcity and labor abundance still prevailed.[25] His estimates of rice production elasticities are not significantly different from Ohkawa's. Their estimates of rice production elasticities are smaller for labor and larger for land than our estimates of aggregate production elasticities.

We do not consider these estimates by Ohkawa and Tsuchiya inconsistent with ours. Their estimates are of rice production, while ours are of aggregate agricultural production, including livestock and sericulture which are less dependent on land.[26] Also, their estimates are for relatively homogeneous regions. As explained previously, interregional variations in the level of agricultural technology, especially between the West and the East, were significant. The estimates by both Ohkawa and Tsuchiya for relatively more homogeneous regions, based on farm survey data, can be considered as estimates of the micro production function of the neoclassical tradition. In contrast, our estimates for the whole nation including technically heterogeneous regions, based on prefectural aggregates, should be of the envelope of the micro production functions — the meta-production function of the Hayami-Ruttan sense.[27] It seems reasonable to infer that disequilibria in the factor inputs, as reflected in the gap between production elasticities and factor shares, are more likely to appear along the surface of a meta-production function involving technical changes.

Recently Masahiko Shintani has attempted to estimate an aggregate agricultural production function in value added terms, based on the farm household economy survey data for 1925-36.[28] His estimates of production elasticities are: 0.3 to 0.5 for labor and 0.1 to 0.2 for capital, which are consistent with ours; but 0.3 to 0.5 for land, is much larger than our estimate. It appears that the large value of the elasticity estimate for land was a result of the specification of the production function in value added terms, subtracting current inputs from gross output. This specification is based on the assumption that the current inputs, such as fertilizer, are paid in the market equal to their marginal value products. It appears possible that, when this equilibrium assumption does not hold, a specification bias emerges in the coefficient of land, which is a close substitute of current inputs.

There have been a number of attempts to estimate aggregate agricultural production functions for the postwar period. A study by Yasuhiko Torii in gross output terms, based on farm economy survey data for 1957-60, is characterized by unstable and somewhat implausible results probably due to excess disaggregation of inputs.[29) However, his estimates of the production elasticity of labor in the range of 0.2 to 0.3 is consistent with our estimate.

Yasuhiko Yuize's estimates of aggregate production elasticities in value added terms, based on the farm economy survey data for 1960 and 1962, are in the ranges of 0.4 to 0.6 for labor, of 0.2 to 0.4 for land, and of 0.2 to 0.5 for capital.[30) Those estimates are, on the whole, consistent with ours, considering that the ratio of value added to gross output in agriculture is about 0.7 in this period.

Ryoshin Minami and Shigeru Ishiwata have estimated the aggregate production function in value added terms by pooling the time-series and the cross-section data from the 1953-65 farm economy surveys, resulting in the estimates of production elasticities — 0.7 for labor, 0.3 for capital, and nearly zero for land.[31)] Their estimate of the labor elasticity appears too high. More implausible is their zero estimate of the land elasticity, considering the fact that the "black market" rent of 50 per cent of produce has often been reported.[32)]

Finally, we will examine the production elasticities of rural education and of agricultural research and extension for which no previous estimates are available for Japanese agriculture. Both the U.S. cross-regional estimates of the aggregate agricultural production function by Griliches and the cross-country study by Hayami and Ruttan have found that the production elasticity of education is equivalent to that of labor, implying a given percentage increase in education which improves the quality of labor, has the same output effect as an equal percentage increase in labor itself.[33)] The present estimates for postwar Japan do not reject the same hypothesis, although they represent very weak evidence because of relatively large standard variations in the coefficients of education. However, the estimates of the production elasticity of education for the prewar period are clearly smaller than those of labor.

A significant increase in the production elasticity of education from the 1930-35 to the 1960-65 periods appears reasonable. Since the late 1950's agricultural producers in Japan have been experiencing dramatic technical and economic changes. As wage rates have risen, they have shifted from a traditional land-saving technology to a new labor-saving technology. At the same time they have adjusted their product mix in favor of commodities characterized by high income elasticities, such as livestock products, vegetables, and fruits, in response to rapid rises in per-capita income. In this situation there is a higher premium on capacity for efficient resource reallocation in response to changes in prices and technology. As a result it seems reasonable that the effects of schooling on agricultural output should have risen significantly.[34)]

In contrast, the inter-war period was characterized by relative stagnation in agricultural technology. Moreover, technical progress, if any, was of a traditional land-saving nature,to which farmers had been accustomed for several generations. Under these conditions, it seems reasonable to expect to find significantly lower estimates of the production elasticity for education for 1930-35 than for 1960-65. It also seems reasonable that the 1930-35 elasticities for Japan are lower than the elasticities estimated by Griliches for the United States in the 1940's and the 1950's, because of the dramatic changes in agricultural technology in the United States during this period.

It is interesting to observe that our estimates of the production elasticity of research and extension for 1930-35 are similar to the Hayami-Ruttan estimates based on the cross-country data and those for 1960-65 similar to the Griliches estimates based on the U.S. cross-regional data. This may be due to a lag in the output effect of agricultural research investment. The real growth in public expenditure for agricultural research has been accelerated in the postwar period, an annual rate of more than 10 per cent as compared with the prewar (1900-35) rate of 5 per cent. Investment in research is, by nature, characterized by a substantial lag in the realization of its output effect as it generally involves a long gestation period. It appears possible that the return on research investment may be characterized by short-run decreasing returns during a period of rapid accumulation of research capital even if research activities are characterized by increasing returns in the long run. In terms of this hypothesis the decline in the coefficient of research and extension from the prewar to the postwar period may not be unreasonable. It might also be that the Griliches estimates for the United States reflect a similar situation.

IV. ACCOUNTING FOR GROWTH

On the basis of the estimates of the aggregate agricultural production function in the previous section we will attempt to account for growth in agricultural output in Japan. Since our production function is assumed to be linear homogeneous the rate of growth in output can be expressed as the sum of growth rates in inputs weighted by the relevant production elasticities. A set of production elasticities primarily based on Regression (7) for the prewar period and on Regression (13) for the postwar period was adopted as shown in Table IV; the choice of the elasticity for education for the postwar period was made on the basis of the previous discussion of the equivalence of labor and education.

TABLE IV

WEIGHTS FOR THE AGGREGATION OF INPUTS

	Labor	Capital	Fertilizer	Land	Education	Res. and ext.
Production elasticities[a]:	(α_L)	(α_K)	(α_F)	(α_A)	(α_E)	(α_R)
1880 - 1900	0.40	0.15	0.08	0.37	0.15	0.03
1900 - 1920	0.40	0.15	0.14	0.31	0.15	0.08
1920 - 1935	0.40	0.15	0.20	0.25	0.15	0.12
1955 - 1965	0.30	0.25	0.20	0.25	0.30	0.05
Factor shares[b]:	(δ_L)	(δ_K)	(δ_F)	(δ_A)		
1880 - 1900	0.51	0.10	0.08	0.31		
1900 - 1920	0.50	0.10	0.10	0.30		
1920 - 1935	0.51	0.11	0.12	0.26		
1955 - 1965	0.51	0.12	0.15	0.22		

a. Based on the estimates of production function in Tables II and III:

$$\alpha_F = \frac{1}{2} \times 0.035\sqrt{\frac{F}{A}} \quad , \qquad \alpha_R = \frac{1}{2} \times 0.06\sqrt{R} \quad ,$$

$$\alpha_A = 1 - (\alpha_L + \alpha_K + \alpha_F) \quad ,$$

b. Saburo Yamada and Yujiro Hayami, Growth Rates of Japanese Agriculture, 1880 -1965, SAP Report No. 1 (Tokyo: Institute of Statistical Research, Inc., August 1971), mimeo.

TABLE V

ACCOUNTING FOR THE GROWTH IN AGRICULTURAL OUTPUT, BASED ON THE ESTIMATES OF PRODUCTION ELASTICITIES, IN TERMS OF ANNUAL COMPOUND RATES OF GROWTH (%)

		Contributions to output growth rates of							
		Conventional Inputs							
	Output	Labor	Capital	Fertilizer	Land	Total	Education	Res. and ext.	Residual
	$(\dot{Y}/Y)$	$\alpha_L(\dot{L}/L)$	$\alpha_K(\dot{K}/K)$	$\alpha_F(\dot{F}/F)$	$\alpha_A(\dot{A}/A)$		$\alpha_E(\dot{E}/E)$	$\alpha_R(\dot{R}/R)$	
Prewar Period : 1880-1935	1.6	-0.11	0.15	0.47	0.15	0.66	0.52	0.44	-0.02
	(100)	(-7)	(9)	(29)	(9)	(40)	(33)	(28)	(-1)
Phase 1 : 1880-1920	1.8	-0.12	0.16	0.40	0.20	0.64	0.54	0.38	0.24
	(100)	(-7)	(9)	(22)	(11)	(35)	(30)	(21)	(14)
I. 1880-1900	1.6	0	0.13	0.14	0.18	0.45	0.45	0.25	0.45
	(100)	(0)	(8)	(9)	(11)	(28)	(28)	(16)	(28)
II. 1900-1920	2.0	-0.24	0.19	0.66	0.22	0.83	0.63	0.51	0.03
	(100)	(-12)	(10)	(33)	(11)	(42)	(31)	(25)	(2)
Phase 2 : 1920-1935	0.9	-0.08	0.13	0.64	0.02	0.71	0.46	0.60	-0.87
	(100)	(-9)	(14)	(71)	(2)	(78)	(51)	(67)	(-96)
Postwar period : 1955-1965	3.6	-0.90	1.57	1.72	0.02	2.41	0.15	0.68	0.36
	(100)	(-25)	(44)	(48)	(0)	(67)	(4)	(19)	(10)
Whole period : 1880-1935 and 1955-1965	1.9	-0.23	0.36	0.66	0.13	0.92	0.46	0.48	0.04
	(100)	(-12)	(19)	(35)	(7)	(49)	(24)	(25)	(2)

Sources: Production elasticities (α's) from Table IV. The growth rates of output and conventional inputs from the same source as for Figure I. The growth rates of research and extension from Saburo Yamada, "Changes in Output and in Conventional and Nonconventional Inputs in Japanese Agriculture Since 1880," op. cit.. The growth rates of education for the prewar period from Masakatsu Akino, "Estimation of Average Years of Formal Education," op. cit.; and the postwar data from the Institute for Economic Research, Economic Planning Agency, Nibumon Seichō Model ni Yoru Keizai Seichōryoku no Sokutei (Estimates of the Potential Growth Rates by Two-Sector Model), Research Series No. 23 (1970).

Inside of parentheses are percentages with the growth rate of output set equal to 100.

TABLE VI

SOURCES OF THE LONG-TERM GROWTH RATES IN TOTAL PRODUCTIVITY IN AGRICULTURE

	Annual compound rates of growth (%)	
	Prewar period 1880-1935	Whole period 1880-1935 and 1955-1965
Total productivity[a]	1.17 (100)	1.44 (100)
Sources explained :		
Change in input weights[b]	0.23 (20)	0.46 (32)
Contribution of education[c]	0.52 (44)	0.46 (32)
Contribution of research and extension	0.44 (38)	0.48 (33)
Unexplained residual	-0.02 (-2)	0.04 (3)

Inside of parentheses are percentages with the growth rate of total productivity set equal to 100.

a. From Table I.

b. Column (Total) in Table V minus Column (Total input) in Table I.

c. From Table V.

Results of the growth accounting, utilizing the production elasticities estimates from Table IV, are summarized in Table V. Each row compares for each period the growth rate in total output in agriculture with the rates of growth in inputs weighted by the production elasticities specified in Table IV. Inside of parentheses is shown the index with the output growth rate set equal to 100.

As a long-term analysis we are successful in reducing the residual in the growth in agricultural output unexplained by the growth in inputs. For the whole period of analysis from 1880 to 1965 excluding the period of war devastation and recovery, as well as for the entire prewar period 1880-1935, the rate of output growth is almost completely explained by changes in four conventional inputs and in education, and in research and extension. As summarized in Table VI, for the whole period, the three major sources: (a) changes in weights for input aggregation from factor shares to production elasticities, (b) contribution of rural education, and (c) contribution of agricultural research and extension are of roughly equal importance in accounting for the growth in the total productivity index, the residual in the growth in output unexplained by the growth in conventional inputs weighted by factor shares. For the prewar period the contribution of education is slightly larger, and the effect of changes in weights smaller.

However, our approach proves inadequate in explaining the variations in the rate of growth in agricultural output and productivity among different phases or "technical epochs." Significant residuals, either positive or negative, remain for the sub-periods. Phase 1 (1880-1920), which was characterized by rapid growth in output and the total productivity index, has a positive residual; and Phase 2 (1920-1935), which was characterized by a relative stagnation in agricultural growth, has a large negative residual. Again, the postwar period of rapid growth is marked by a positive residual.

These sequences in which either a positive or negative residual appears seem explainable in terms of sequences in the accumulation and exhaustion of the potential in agricultural technology as analyzed by Hayami and Yamada.[35)] According to the Hayami-Yamada hypothesis rapid growth in Phase 1 was supported by a backlog of technological potential accumulated during the feudal Tokugawa period, a process of nation-wide diffusion of superior methods and advanced knowledge embodied in veteran farmers (Rōnō) in various localities, which had hitherto been dammed by feudal constraints until they were removed by the Meiji reforms. Exploitation and diffusion of the backlog of indigenous technology were also facilitated by the government's agricultural research and extension activities and by the introduction of modern communication and transportation systems including postal service and railway.

Stagnation in Phase 2 resulted from the exhaustion of this technological potential as the result of its diffusion before the modern agricultural research system began to supply new potential in sufficient amounts. The postwar spurt was based, at least in part, on realization of the technological potential which was accumulated during the war period as the result of massive research investments, domestic and foreign, for military purposes. Most of the researches conducted during the war were not for agricultural purposes, but they formed a backlog for the advancements in agricultural techniques.[36]

When a backlog of potential technology has been accumulated, agricultural research tends to have a higher pay-off by exploiting the existing potential. When the potential is exhausted, research investment is likely to yield lower returns, at least in the short run, until it produces major breakthroughs. Also, returns to formal education would be higher during a period of rapid technical progress, as discussed previously.

It seems reasonable to hypothesize that the positive residuals for Phase 1 and the postwar spurt period, in contrast to the negative residual for Phase 2, have resulted from the neglect in our model of those effects of accumulation and exhaustion of technological potential over time. It is also hypothesized that the large residual for Phase 2 is partly attributable to the influence of depressed agricultural prices due to the large scale import of colonial rice and to the contraction of demand in the inter-war recession, which dampened farmers incentives to introduce new technology.[37]

V. CONCLUSION

In this study, by estimating the aggregate agricultural production function using cross-prefectural data, factors have been identified that could influence the level of agricultural output. With the estimates of production elasticities, the major portion of the growth in agricultural output and productivity for 1880-1965 has been explained by the four conventional factors—land, labor, capital, and fertilizer—and the two categories of nonconventional inputs—rural education, and agricultural research and extension.

Overall, about half of the long-term rate of growth in agricultural output has been accounted for by changes in the four conventional inputs; one-quarter by an increase in the level of education; and another one-quarter by an increase in the public expenditure for agricultural research and extension. A large gap between the growth in output and the growth in conventional inputs, as measured by the total productivity index, has been closed and accounted for in roughly equal magnitudes by: (a) adoption of the estimates of production elasticities for input aggregation; (b) the contribution of education; and (c) the contribution of research and extension. The divergence between the production elasticities and the factor shares has been interpreted as arising from a lag in the adjustment of farmers to biased technical progress corresponding to changes in relative factor prices.

Our approach has proved insufficient for explaining the emergence of distinct phases or technical epochs in the modern agricultural development of Japan. Significant residuals in the growth accounting have remained for sub-periods. The sequences in which positive and negative residuals appear for different phases have been found consistent with the Hayami-Yamada hypothesis concerning the sequences of accumulation and exhaustion of technological potential over time.

It must be emphasized that our approach is a very rough first approximation, and that we should be cautious in deriving any theory and policy implications from the results of this study. In addition to the problems involved in data and estimation procedures, the present approach has an intrinsic weakness in that interactions among factors can not be properly analyzed. Improvements in land-saving technology (for example, the development of high-yielding seed varieties) may not be effective unless accompanied by increases in the application of fertilizer and other agricultural chemicals. The effects of labor-saving innovations may not be realized without investment in new machinery. The pay-off to investment in education is not independent of the speed of technical progress. The growth accounting analysis based on aggregative data as in this study, is most useful for the understanding of the agricultural development process when complemented by micro case studies which analyze the intrinsic interactions among conventional and nonconventional factors.

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Notes

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1) For examples see B.F. Johnston, "Agricultural Productivity and Economic Development in Japan," Journal of Political Economy, Vol.59 (December 1951), pp. 498-513; and Kazushi Ohkawa and Henry Rosovsky, "The Role of Agriculture in Modern Japanese Economic Development," Economic Development and Cultural Change, Vol. 9 (October 1960), pp. 43-67.

2) Zvi Griliches, "Research Expenditures, Education and the Aggregate Agricultural Production Function," American Economic Review, Vol. 54 (December 1964), pp. 961-74. For more detailed theoretical discussions on the growth accounting approach, see D.W. Jorgenson and Zvi Griliches, "The Explanation of Productivity Change," Review of Economic Studies, Vol. 34 (July 1964), pp. 249-83.

3) Yujiro Hayami and Saburo Yamada, "Technical Progress in Agriculture," in L.R. Klein and Kazushi Ohkawa (eds.), Economic Growth:

The Japanese Experience Since the Meiji Era (Homewood, Ill.: Irwin, 1968), pp. 135-61.

4) This section draws on the data compiled in Saburo Yamada and Yujiro Hayami, Growth Rates of Japanese Agriculture, 1880-1965, paper presented at the conference on Agricultural Growth in Japan, Korea, Taiwan and the Philippines, sponsored by the East-West Center Food Institute and the University of Minnesota Economic Development Center, held at Honolulu, Hawaii, February 6-9,1973.

5) R.R. Nelson, "Aggregate Production Functions and Medium Range Growth Projections," American Economic Review, Vol. 54 (September 1964), pp. 575-606.

6) See Chapters 6 and 7 of Yujiro Hayami and V.W. Ruttan, Agricultural Development: An International Perspective (Baltimore: The Johns Hopkins Press, 1971), pp. 111-66.

7) Factor shares in Japanese Agriculture for 1880-1965 are estimated in Hayami and Yamada, Growth Rates . . . , op. cit..

8) T.W. Schultz, Transforming Traditional Agriculture (New Haven, Conn.: Yale University Press, 1964), pp. 145-53.

9) R.E. Evenson, "Economic Aspects of the Organization of Agricultural Research," in W.L. Fishel (ed.), Resource Allocation in Agricultural Research (Minneapolis: University of Minnesota Press, 1971), pp. 103-82.

10) Saburo Yamada, "Changes in Output and in Conventional and Nonconventional Inputs in Japanese Agriculture Since 1880," Food Research Institute Studies, Vol. 7, No. 3 (1967), pp. 371-413.

11) Evenson, "Economic Aspects . . . ," op. cit..

12) Hayami and Yamada, "Technical Progress . . . ," op. cit..

13) Yujiro Hayami, "Hiryō Jyuyō Kōzō no Henka to Nōgyō Hatten no Nikyokumen," (Structural Changes in Fertilizer Demand and the Two Phases of Japanese Agricultural Development) Economic Studies Quarterly, Vol. 17 (March 1967), pp. 27-35.

14) See the surveys by Keizo Tsuchiya, "Nihon Nōgyō no Keiryōteki Bunseki: Tenbō," (Econometric Analysis of Japanese Agriculture: Survey) Economic Studies Quarterly, Vol. 17 (March 1967) pp. 50-64; and Nōgyō Keizai no Keiryō Bunseki (Econometric Analysis of Agricultural Economy; Tokyo: Keiso Shobo, 1962), pp. 14-25.

15) Yasuhiko Yuize, "Nōgyō ni okeru Kyoshiteki Seisankansū no Keisoku," (The Aggregate Production Function in Agriculture) Nōgyō Sōgō Kenkyū, Vol. 18 (October 1964), pp. 1-54, estimates increasing returns; whereas, Yasuhiko Torii, "Nōgyō Bumon no Genkaiseisanryoku Sokutei," (Measurement of Agricultural Marginal Productivity) Economic Studies Quarterly, Vol. 16 (June 1966) pp. 52-66, indicates constant returns prevailing.

16) Masakatsu Akino, "Nōgyō Seisan Kansū no Keisoku," (Estimation of Agricultural Production Function) Nōgyō Sōgō Kenkyū, Vol. 26, No. 2 (April 1972).

17) More detailed explanations of data are available in Ibid..

18) Ibid..

19) The null hypotheses of the equality of the production parameters between 1930 and 1935, and between 1960 and 1965, are accepted

according to the results of analysis of variance: the F-statistics are calculated as 0.80 between Regressions (1) and (3); as 1.09 between Regressions (2) and (4); as 0.98 between Regressions (8) and (10); and as 1.10 between Regressions (9) and (11).

20) See, for the factor share estimates, Yamada and Hayami, Growth Rates . . . , op. cit..

21) Hayami and Ruttan, Agricultural Development, op. cit., pp. 111-35.

22) According to an estimate by Akino based on experimental data, the level of input of nitrogen in an average farm in Japan in the 1930's was 50 to 100 per cent lower than the optimum level. See Akino, "Estimation of Agricultural Production Function," op. cit..

23) Griliches, "Research Expenditure, . . . ," op. cit..

24) Kazushi Ohkawa, Shokuryō Keizai no Riron to Keisoku (Theory and Measurement of Food Economy; Tokyo: Nihonhyoronsha, 1945), pp. 145-63.

25) Tsuchiya, Econometric Analysis. . . , op. cit., pp. 29-40.

26) Ohkawa's estimates for 1940-41 suggest lower production elasticities of land even for such winter crops as wheat, barley, and naked barley. Ohkawa, Theory and Measurement of Food Economy, op. cit., pp. 164-97.

27) For the concept of the meta-production function, see Hayami and Ruttan, Agricultural Development, op. cit., pp. 82-85 and 122-28.

28) Masahiko Shintani, Senzen Nihon Nōgyō no Gijutsu Shimpo to Fukyu ni Kansuru Bunseki (Technological Innovation and its Diffusion in Prewar Japanese Agriculture; Paper presented at the Annual Meeting of the Japanese Association of Theoretical Economics in 1971, Tokyo).

29) Torii, "Measurement of Agricultural . . . ," op. cit..

30) Yuize, "The Aggregate Production . . . ," op. cit..

31) Ryoshin Minami and Shigeru Ishiwata, "Nōgyō no Seisan Kansū to Gijutsu Shimpo, 1953-1965," (Production Function and Technical Progress in Agriculture) Keizai Kenkyū, Vol. 20 (July 1969), pp. 226-36.

32) Official rents under the regulations of the Land Reform laws can not be considered to reflect the marginal productivity of land in agriculture.

33) Griliches, "Research Expenditure . . . ," op. cit.; and Hayami and Ruttan, Agricultural Development, op. cit., pp. 86-107.

34) For discussions on the dependency of returns to schooling on technical progress, see Finis Welch, "Education in Production," Journal of Political Economy, Vol. 78 (January-February 1970), pp. 35-57.

35) Hayami and Yamada, "Technical Progress . . . ," op. cit..

36) For historical descriptions, see Hayami and Ruttan, Agricultural Development, op. cit., pp. 153-64.

37) Ibid., pp. 218-27.