Title	Aggregation of Self-Supplied and Commercial Fertilizer Inputs : Some Implications on Japanese Agricultural Stagnation of the 1920's
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Citation	Journal of the Faculty of Agriculture, Hokkaido University, 58(1), 13-26
Issue Date	1975-01
Doc URL	https://hdl.handle.net/2115/12892
Type	departmental bulletin paper
File Information	58(1)_p13-26.pdf

AGGREGATION OF SELF-SUPPLIED AND COMMERCIAL FERTILIZER INPUTS; SOME IMPLICATIONS ON JAPANESE AGRICULTURAL STAGNATION OF THE 1920'S*

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Received August 13, 1974

According to OHKAWA's classification, Phase II of Japanese agricultural development, dated from 1917 to 1937, is characterized by the low growth rate of total productivity[1]. This low growth rate of total productivity, due to a low growth rate of total output and a high growth rate of total input, is broadly known as the "Japanese Agricultural Stagnation of the 1920's". Following OHKAWA's general view, HAYAMI and RUTTAN[2], and recently SHINTANI[3] have attempted to explain the stagnation in Phase II by factors other than conventional inputs such as land, labor, fertilizers, etc.. HAYAMI and RUTTAN explained the Japanese agricultural stagnation in the 1920's by (a) the slowdown of technological progress, reflected in the slower rise in the seed improvement index of rice, and (b) the increase in imports of rice from Korea and Taiwan. SHINTANI viewed the stagnation as result

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* This paper was reported at the Agricultural Economic Society of Japan held at Kyoto University, April 1974.

We are indebted to Dr. Toshio KUROYANAGI (Associate Professor, Hokkaido University) and Dr. Masakatsu AKINO (Associate Professor, University of Tokyo) for helpful comments on an earlier draft of this paper.

[1] OHKAWA, Kazushi, Bruce F. JOHNSTON and Hiromitsu KANEDA; "Agricultural and Economic Growth: Japan's Experience", University of Tokyo Press, 1969. The annual growth rates of total output, total input and total productivity constructed by Saburo YAMADA corresponding to relevant development phases are as follows:

	1882-1917	1917-1937	1947-1957
Total output	1.78	0.82	4.51
Total input	0.28	0.28	1.41
Total productivity	1.49	0.49	3.05

[2] HAYAMI, Yujiro and VERNON W. RUTTAN; "Agricultural Development", The Johns Hopkins Press, 1971.

[3] SHINTANI, Masahiko; "Technological Change and Stagnation of Production in Prewar Japanese Agriculture", Journal of Rural Economics, Vol. 44, 1972 (edited by the Agricultural Economic Society of Japan).

of a change from capital intensive to labor intensive technology in the agricultural sector. Though these authors demonstrated many interesting aspects of the problem, from the following standpoints one will see that their arguments are no longer undisputed: (1) The seed improvement index of rice used in HAYAMI-RUTTAN's paper is unquestionably a good yardstick of the national average yield of rice at the actual farm level, but there is no reason for one to believe that it is an adequate representative of the potential technological level existing in the period concerned. Clearly, HAYAMI and RUTTAN have neglected the inflow of new technology supplied by the national and prefectural experiment stations which were established before the agricultural sector entered the stagnation phase. (2) Since labor intensive technological progress seems generally not to be induced in a period of high labor price, SHINTANI's view is theoretically unappreciated. (3) The arguments of HAYAMI-RUTTAN and SHINTANI appear inconsistent with the result of a recent work of AKINO and HAYAMI[4].

Subject to space limitations, we can not deal with the entire problem in this paper. This paper, as part of our recent work[5], has the primary purpose of testing the hypothesis of the low fertilizer input level in the period 1917–1929. To fulfill this purpose, first the elasticity of substitution between self-supplied and commercial fertilizer inputs is estimated and second, the two fertilizer inputs are reaggregated into single effective input indices[6].

The analysis comes to conclude that the estimated effective level of

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4) AKINO, Masakatsu and Yujiro HAYAMI, "Sources of Agricultural Growth in Japan, 1880–1965", The Quarterly Journal of Economics, Vol. 88, 1974.

5) Le Thanh NGHIEP, "Agricultural Stagnation in Prewar Japan: Its causes and Implications to Economic Development Strategy", unpublished paper. While the input index of fertilizer is computed in this paper to prove that the total input index (of which fertilizer is a component) constructed by Saburo YAMADA (see YAMADA, Saburo, "Changes in Output and in Conventional and Nonconventional Inputs in Japanese Agriculture since 1880 "Food Research Institute Studies, Vol. 7, No. 3 (1967)) overestimates the total input in the period 1917–1929, the above mentioned paper explicitly searched for the causes of the stagnation through supply analysis. The analysis comes to conclude that the unprecedently high rate of migratory movement of labor out of the agricultural sector was the main cause of the agricultural stagnation of the 1920's. The stagnation was a natural consequence of the labor intensive economic development of the non-agricultural sector in a period where the quantities as well as the using techniques of new factors such as machinery and chemical fertilizers were not well developed and widely diffused to cover the damage brought about by the decrease in labor input.

6) The word "effective" is used to indicate that the underlying elasticity of substitution is under consideration. As will be discussed in Section I, the linear function which has been often used, implicitly assumes an elasticity of substitution equal to infinite.

total fertilizer input in the period 1917–1929 is not as high as that has been thought, and that this low level of total fertilizer input was apparently attributable to the low growth rate of self-supplied fertilizers within this period.

I-ESTIMATION METHODS AND DATA

Methods to be selected and derived results regarding any aggregation of two productive factors are considered as crucially dependent on the assumed value of the elasticity of substitution between these two factors. In other words, to aggregate two productive factors over a given period, information about substitutional technology related to these two factors in this period is required. There seem to be two ways to get this information:

a-Search for the related information from authoritative specialists.

b-Estimate the elasticity of substitution directly from the data about prices and quantities of factor input with adequate assumptions.

We chose the latter method in this paper. This decision was based on the following two reasons: (1) It is not a little difficult to find such technological information suitable for the purpose of the paper. (2) Because in Japan most technological reports are based on experimental results performed at various national and prefectural experiment stations, and since it is a common belief that there is a substantial gap between technological levels at these experiment stations and at actual farms, direct estimation is also a useful approach even when this information is offered.

Now, consider the production function[7]:

$$Y_t = Y(F_{1t}, F_{2t}, X_t) \qquad (1)$$

where,

Y_t: Quantity of agricultural output at time t.
F_{1t}: Quantity of self-supplied fertilizer input at time t.
F_{2t}: Quantity of commercial fertilizer input at time t.
X_t: Quantities of all kinds of input other than fertilizers at time t.

The aggregation of F_1 and F_2 requires that function (1) could be rewritten as:

$$Y_t = Y\left[F(F_{1t}, F_{2t}),\ X_t\right] \qquad (2)$$

where,

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[7] Samuel Bowles applied a same method to estimate the elasticities of substitution among labor with different levels of schooling. See Samuel Bowles, "Aggregation of Labor Inputs…", The Journal of Political Economy, Vol. 78, No. 1, 1970.

$$F_t = F(F_{1t}, F_{2t}) \qquad (3)$$

is the function to be searched for.

Function (2) presents the technical relationship between F and X to produce (agricultural product) Y when function (3) presents the technical relationship between F_1 and F_2 to produce (fertilizer service) F. Careful notice of the problems of F_1 and F_2 within F and of F and X within Y should be taken if the arguments developed below are to be followed without confusion.

Until the present day, function (3) has been usually given by the form:

$$F_t = P_1 F_{1t} + P_2 F_{2t} \qquad (4)$$

where P_1 and P_2 are constant weights, generally presented by average prices of the two factors F_1 and F_2. Function (4) implies an assumed infinite elasticity of substitution which turns out to be questionable. First, assuming a special value for the elasticity of substitution without any inspection upon the underlying substitutional relationship concerned to the two productive factors is theoretically not perceptible. Second, the data illustrated in Table 1 and Figure 1 seem to ensure an elasticity of substitution of some value virtually lower than infinite. In the case of the isoquant (I_1) (nearly

TABLE 1. Input Values and Prices of Fertilizers (1899–1932)

Year	F_1	F_2	Price Index of F_1	Price Index of F_2
	(1,000 ¥)		(1934–1936 : 100)	
1899	77,363	35,935	36.0	122.3
1902	100,137	41,815	45.5	97.0
1905	102,762	60,207	46.2	128.0
1908	131,395	76,204	57.4	106.2
1911	148,508	110,451	62.4	107.0
1914	142,248	124,532	57.9	119.6
1917	182,458	184,975	72.8	143.9
1920	404,427	422,782	161.1	268.6
1923	304,176	290,133	117.6	161.2
1926	339,520	343,152	133.0	154.5
1929	334,740	311,169	126.3	125.6
1932	260,270	200,255	89.0	89.4

Notes: F_1: Self-supplied Fertilizers.
F_2: Commercial Fertilizers.

Source: Hayami, Yujiro, "*Hiryo Tokaryo no Suikei*" (Estimation of Fertilizer Input), *Nogyo Sogo Kenkyu*, Vol. 17, No. 1, 1963.

infinite elasticity of substitution), the input level of F_1 falls substantially from F_{11} to F_{12} as result of a rise in the price of F_1 when with a similar rise in the price of F_1, the input level of F_1 shows a small decline from OF_{11} to $OF_{12'}$ in the case of the isoquant (I_2) (small elasticity of substitution). Whenever $\partial > \partial'$, the inequalities $OF_{11}-OF_{12} > OF_{11}-OF_{12'}$ and $OF_{22}-OF_{21} > OF_{22'}-OF_{21}$ are satisfied. Thus, the smaller the elasticity of substitution is, the smaller is the change in the rate of two fertilizer inputs. In prewar Japanese agriculture, as illustrated in Table 1, the absolute input level of self-supplied fertilizers even increased despite the fact that the relative price of self-supplied and commercial fertilizers rose constantly. This, together with Figure 1, reveals a rather low elasticity of substitution.

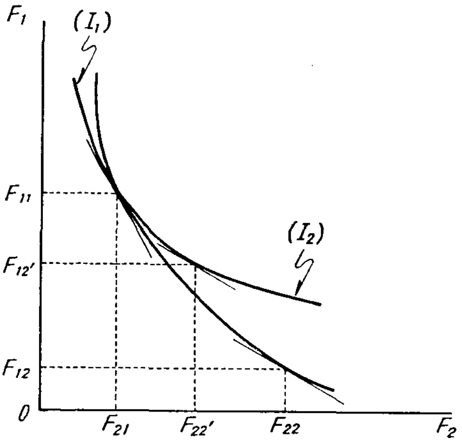

Figure 1. Changes in the rate of two factor inputs.

Now let us specify function (3) in the form of :

$$F_t = (d_1 F_{1t}^{-v} + d_2 F_{2t}^{-v})^{-\frac{1}{v}} \tag{5}$$

where,

$\sigma = \dfrac{1}{1+v}$ is the elasticity of substitution,

d_1, d_2 : constants with $d_1 + d_2 = 1$.

Take partial derivatives of F_t with respect to F_{1t} and F_{2t},

$$M_{1t} = \frac{\partial F_t}{\partial F_{1t}} = (d_1 F_{1t}^{-v} + d_2 F_{2t}^{-v})^{-\frac{1}{v}-1} d_1 F_{1t}^{-v-1} \tag{6}$$

$$M_{2t} = \frac{\partial F_t}{\partial F_{2t}} = (d_1 F_{1t}^{-v} + d_2 F_{2t}^{-v})^{-\frac{1}{v}-1} d_2 F_{2t}^{-v-1} \tag{7}$$

and put

$$\frac{M_{2t}}{M_{1t}} e^{at} = \frac{P_{2t}}{P_{1t}} U_t \tag{8}$$

where,

P_{1t} : price of self-supplied fertilizers at time t,
P_{2t} : price of commercial fertilizers at time t,
a : constant coefficient,
U_t : disturbance term.

Then,

$$\frac{F_{2t}}{F_{1t}}=\left(\frac{d_2}{d_1}\right)^{\sigma}\left(\frac{P_{1t}}{P_{2t}}\right)^{\sigma}e^{\sigma at}\,U_t \tag{9}$$

Notice that whenever the level of all inputs other than these two kinds of fertilizer influence their marginal productivities in different ways, $\frac{M_{2t}}{M_{1t}}$ does not best present the proportion of the two marginal productivities, so as to equal their price rate. Since most improved seeds responded more to chemical fertilizers and since land improvements tended to reduce land exhaustion, it is believed that the investments in seed and land improvements largely resulted in the expansion of commercial fertilizer consumption. That is to say, these investments tended to raise the marginal productivity of commercial fertilizers over that of self-supplied fertilizers at any given rate of these two factors[8]. Equation (8) assumes an annual rate of *a*% of this biased technical progress. The parameter *a* is expected to be positive.

Now, if the adjustment of $\frac{F_{2t}}{F_{1t}}$ is allowed to be spread over more than one year, one will obtain the Nerlovian adjustment function[9]:

$$\frac{F_{2t}}{F_{1t}}=\left(\frac{d_2}{d_1}\right)^{\gamma\sigma}\left(\frac{P_{1t}}{P_{2t}}\right)^{\gamma\sigma}e^{\gamma\sigma at}\left(\frac{F_{1t-1}}{F_{1t-1}}\right)^{(1-\gamma)}U_t^{\gamma\sigma} \tag{10}$$

where γ is the coefficient of adjustment.

If lower case letters stand for the logarithms, equations (9) and (10) reduce to:

$$(f_{2t}-f_{1t})=\sigma\ln\frac{d_2}{d_1}+\sigma(p_{1t}-p_{2t})+\sigma at+\sigma u_t \tag{11}$$

$$(f_{2t}-f_{1t})=\gamma\sigma\ln\frac{d_2}{d_1}+\gamma\sigma(p_{1t}-p_{2t})+\gamma\sigma at+(1-\gamma)(f_{2t-1}-f_{1t-1})+\gamma\sigma u_t \tag{12}$$

There is still some question whether one could assume a constant elasticity of substitution over the long period 1899–1929. Further, MARUYAMA

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[8] Explicitly $\frac{\partial Y_t/\partial F_{2t}}{\partial Y_t/\partial F_{1t}}=\frac{\partial F_t/\partial F_{2t}}{\partial F_t/\partial F_{1t}}\,e^{at}$ is assumed.

[9] Instead of Eq. (9), put:

$$(F_{2t}/F_{1t})^*=(d_2/d_1)^{\sigma}(P_{1t}/P_{2t})^{\gamma}\,e^{\sigma at}\,U_t^{\sigma}$$

where $(F_{2t}/F_{1t})^*$ represents the equilibrium level of (F_{2t}/F_{1t}). Then, assume the Nerlovian adjustment of this equilibrium level:

$$\frac{(F_{2t}/F_{1t})}{(F_{2t-1}/F_{1t-1})}=\left[\frac{(F_{2t}/F_{1t})^*}{(F_{2t-1}/F_{1t-1})}\right]^{\gamma}$$

suggested that the increase of inorganic fertilizer input in the 1920's might excuse the low yield of rice production in this period[10]. If MARUYAMA's suggestion is true, the proportion of inorganic fertilizer input to total commercial fertilizer input may be included as an exponent for the elasticity of substitution between self-supplied and commercial fertilizers. If we put $\sigma_t = \sigma_0 + \sigma_1 Z_t$ (Z_t is the proportion of inorganic fertilizer input to total commercial fertilizer input), equation (12) converts to:

$$
\begin{aligned}
(f_{2t}-f_{1t}) = {} & \gamma\sigma_0 \ln\frac{d_2}{d_1} + \gamma\sigma_1 \ln\frac{d_2}{d_1} Z_t + \gamma\sigma_0(p_{1t}-p_{2t}) \\
& + \gamma\sigma_1(p_{1t}-p_{2t}) Z_t + (1-\gamma)(f_{2t}-f_{1t}) \\
& + \gamma\sigma_0 at + \gamma\sigma_1 atZ_t + \gamma(\sigma_0+\sigma_1 Z_t) u_t \qquad (13)
\end{aligned}
$$

where σ_1 is expected to be negative.

Then, there will be seven numerical values to compute five structural parameters. This therefore calls for the non-linear regression method if unique estimates of $\frac{d_2}{d_1}$, σ_0, σ_1, γ and a are to be obtained.[11]

II-ESTIMATION RESULTS

The regression of equations (11) and (12), by the linear least squares method, and, of equation (13), by the non-linear least squares method have been fitted to the relevant data of the period 1899–1929. Data used in these regressions are as follows:

F_{1t}: Input value of self-supplied fertilizers deflated by the price index of self-supplied fertilizers at time t.

F_{2t}: Input value of commercial fertilizers deflated by the price index of commercial fertilizers at time t.

P_{1t}: Price index of self-supplied fertilizers at time t.

P_{2t}: Price index of commercial fertilizers at time t.

All data about price and input value of the two kinds of fertilizer are based on HAYAMI's estimates[12]. Estimation results are presented in Table 2.

Close inspection of the computed standard errors reveals that all estimates, except that of variable Z_t, are significantly non-zero at levels lower

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[10] MARUYAMA, Noboru, "Development of Fertilization for Rice Culture in Japan".

[11] The non-linear estimation procedure is explained in detail by, for examples, Behrman, Jere R., "Supply Response in Underdeveloped Agriculture", North-Holland, 1968 and Golfelf, Stephen M. and Richard E. QUANDT, "Nonlinear Methods in Econometrics", North-Holland, 1972.

[12] HAYAMI, Yujiro, *"Hiryo Tokaryo no Suikei"* (Estimation of Fertilizer Input), *Nogyo Sogo Kenkyu*, 1963.

TABLE 2. Estimation Results

Regression Equation	Reduced Form Parameters				Structural Parameters					$\bar{R}^2$ (adjusted)	d
	$\ln \frac{P_{1t}}{P_{2t}}$	$\ln \frac{F_{2t-1}}{F_{1t-1}}$	t	Constant	σ or σ_0	σ_1	γ	a	$\ln \frac{d_2}{d_1}$		
Eq. (11)	.368*** (.154)		.050*** (.005)	-1.478	.368			.050	-4.020	.965	.654
Eq. (12)	.290*** (.126)	.540*** (.135)	.018** (.009)	- .496	.631		.459	.063	-1.711	.971	1.936
Eq. (13)					.686*** (.205)	-.254* (.166)	.498*** (.121)	.059*** (.024)	-1.672*** (.770)	.990	1.946

Notes:
1) The parameters of equations (11) and (12) are estimated by least squares method while the parameters of equation (13) are estimated directly by nonlinear regression method.
2) ***, **, *: t-tests indicate that these estimates are significantly non-zero at respectively 2.5%, 5% and 10% levels.
3) The figures in parentheses are standard-errors.
4) Data used are based on HAYAMI's estimates (see "*Hiryo Tokaryo no Suikei*" (Estimation of Fertilizer Inputs), *Nogyo Sogo Kenkyu*, Vol. 17, No. 1, 1963.

than 5%. High values of the adjusted coefficient of determination indicate the independent variables included account for most of variations in the rate of commercial and self-supplied fertilizer inputs throughout the period concerned. The introduction of the variable Z_t makes it possible to specify an elasticity of substitution changing through time and results in some improvement on the level of the adjusted coefficient of determination.

The following two points can be particularly picked up from the estimation results presented in Table 2:

1—The estimation results support the primary hypothesis in favor of a low elasticity of substitution between the two kinds of fertilizer in prewar Japan. Though relaxing the assumption of constant elasticity does not provide substantial changes in the effective index of fertilizer input, the negative estimate obtained for the variable Z_t is worthy of deep interest13).

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13) The negative sign obtained for the parameter of the variable Z_t indicates that farmers of those days hesitated to substitute inorganic fertilizers for self-supplied fertilizers. However, it seems meaningful to add some words of reservation. This analysis does not deny the role of chemical fertilizers in raising land productivity. Though the underlying technical progress had some tendency of raising commercial fertilizer consumption, MARUYAMA has pointed that factors such as methods of fertilization and improvement of seed and land were not well developed to make rice plant possibly absorb large part of nutritive elements embodied in fertilizers which were actually scattered. Rice production in Japan has attained high yield after World War II despite the fact that the share of inorganic fertilizers within total fertilizers consumed has increased year to year. Thus, it is not the increase of inorganic fertilizers but the lack of accompanied technical progress in the 1920's that must be accused for the minus sign obtained for the parameter of Z_t.

2—The parameter a of the variable t has a positive sign. This confirms an annual increasing rate of about 6% in the ratio of the marginal productivity of commercial fertilizers to the marginal productivity of self-supplied fertilizers at each constant rate of these two inputs. This means there existed some elements in the agricultural sector which raised the marginal productivity of commercial fertilizers to an annual rate of 6% over that of self-supplied fertilizers. The question of what should be regarded as attributable for this biased influence on these two productivities is still unsolved within the frame of this analysis. However, as many specialists have mentioned, investments on seed and land improvements may be taken as its prime origins.

III-INDICES OF FERTILIZER INPUT AND SOME CONCLUDING REMARKS

Alternative indices of fertilizer input are constructed by substituting the estimates of σ, d_1 and d_2 for those parameters in equation (5). The computation results are illustrated in Table 3 and Figure 2, where F', F'' and F''' stand for indices with the elasticity of substitution assumed to be ∞, 0.631 and $(0.686\text{–}0.256\,Z_t)$ respectively. The annual growth rates of alternative indices are presented in Table 4. F'' and F''' rise up almost at a same rate with F' till 1917, and indicate a low growth rate after that year. Therefore, the indices F'' and F''' strongly support the hypothesis of low fertilizer input in the 1920's, in contrast with what has been broadly achieved.

Figures of fertilizer input presented in this section and those of elasticity of substitution illustrated in the previous section allow one to point out the following implicative remarks as conclusions for this paper :

1. The effective indices of fertilizer input calculated from CES equations show a low growth rate in the 1920's. This low growth rate is likely responsible, to some extent, for the agricultural stagnation in this period. The argument can be shortly proved as follows :

—Assume that one attempts to explain the variations in yields of rice and agricultural products singly by fertilizer input. The figures in Table 5 prove that F'' and F''' do their job better than F' in all cases. As shown in the table, the coefficients of determination of the regression equations including F'' and F''' are higher than those of the regression equations including F'.

—The effectiveness of F'' and F''' is also appreciable through inspec-

TABLE 3. Alternative Indices of Fertilizer Input (1899–1929)
(1899 = 100.0)

Years	F'	F''	F'''
1899	100.0	100.0	100.0
1900	103.4	106.2	105.4
1901	107.5	112.1	110.7
1902	111.0	116.7	115.2
1903	114.6	120.8	117.9
1904	107.3	111.8	107.9
1905	114.3	121.0	115.9
1906	118.5	125.8	120.0
1907	127.4	135.7	128.6
1908	132.1	140.4	133.7
1909	142.3	148.0	141.1
1910	142.5	149.3	141.5
1911	153.9	159.0	150.8
1912	153.1	159.1	151.0
1913	167.8	168.5	159.8
1914	158.3	163.2	154.7
1915	160.3	165.3	157.5
1916	163.8	167.9	160.0
1917	175.0	174.1	165.6
1918	183.1	176.0	167.0
1919	211.9	189.0	178.0
1920	192.9	182.2	172·0
1921	192.0	183.2	173.6
1922	192.0	183.2	173.5
1923	210.5	191.7	181.4
1924	204.3	187.1	177.0
1925	209.7	190.0	179.7
1926	234.1	197.2	186.3
1927	237.4	201.2	190.0
1928	241.0	200.7	189.6
1929	254.3	207.1	195.5

Notes: F' is estimated by the equation $F' = \bar{P}_1 F_1 + \bar{F}_2 F_2$ where $\bar{P}_1$ and $\bar{P}_2$ are cross-year average prices of self-supplied and commercial fertilizers.

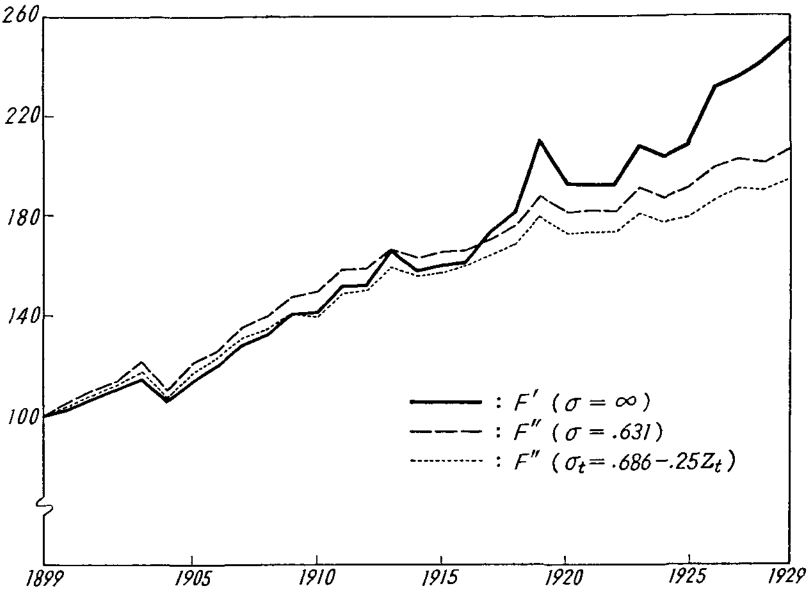
F'' is estimated by the equation:

$$F'' = \left[d_1 F_1^{\frac{\sigma-1}{\sigma}} + d_2 F_2^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}} \qquad \text{with } \sigma = 0.631$$

F''' is estimated by the equation:

$$F_t''' = \left[d_1 F_{1t}^{\frac{\sigma_t-1}{\sigma_t}} + d_2 F_{2t}^{\frac{\sigma_t-1}{\sigma_t}} \right]^{\frac{\sigma_t}{\sigma_t-1}} \qquad \text{with } \sigma_t = 0.683\text{–}0.25\, Z_t$$

and Z_t is the proportion of inorganic fertilizers to total commercial fertilizers.



Note: See Table 3.

Figure 2. Alternative Indices of Fertilizer Input

TABLE 4. Annual Growth Rates of Alternative Indices

Periods	F'	F''	F'''
1899-1917	3.2	3.2	2.9
1917-1929	3.2	1.4	1.4

tions of AKINO-HAYAMI's recent paper[14]. With a notable exception for the period 1920–1936, AKINO and HAYAMI successfully explained the sources of Japanese agricultural growth during the period 1883–1936 by adapting the estimated parameters of a COBB-DOUGLAS production function derived from 1930's data. Since the two authors carefully treated important non-conventional inputs such as quality of labor and research expenditures, and since the production function was estimated from 1930's data, the exceptional unsuccess for the period 1920–1936 can not be accounted for by HAYAMI-RUTTAN's seed index or SHINTANI's biased technical progress. It is reasonable for one to think that one or some inputs have been overestimated. Then the sizable negative residual obtained for Phase II by these two

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[14] See footnote 4.

TABLE 5. Yield Functions of Rice and Agricultural Products

Commodities		R^2	d
Rice	$LnYR = 6.335 + \underset{(.061)}{.331^{***}}\ Ln\frac{F'}{A}$	.50	2.223
	$LnYR = 6.929 + \underset{(.082)}{.494^{***}}\ Ln\frac{F''}{A}$	.56	2.514
	$LnYR = 7.090 + \underset{(.096)}{.533^{***}}\ Ln\frac{F'''}{A}$	.55	2.480
Agricultural Products	$LnYA = 7.574 + \underset{(.044)}{.412^{***}}\ Ln\frac{F'}{A}$	.75	1.779
	$LnYA = 8.232 + \underset{(.059)}{.593^{***}}\ Ln\frac{F''}{A}$	.78	1.974
	$LnYA = 8.444 + \underset{(.065)}{.644^{***}}\ Ln\frac{F'''}{A}$	.77	1.997

Notes 1) The figures in parentheses are standard errors.
2) ***: *t*-tests indicate that these estimates are significantly nonzero at 2.5%.
3) The variables are as follows:
YR: Yield of rice,
YA: Yield of agricultural products,
A : Total arable land,
F', F'', F''': Alternative indices of fertilizer input.

authors may be substantially reduced by the newly constructed indices of fertilizer input F'' and F'''.

2. Low elasticity of substitution implies that the input index to be constructed is subject to both input factors. When one of these two components is held constant, the effective index can not largely increase, however speedy the increase of the other component. Thus, the growth rate of the effective indices of fertilizer input in Phase II was certainly pushed down by the low growth rate of self-supplied fertilizers in this period. Then, what was responsible for this low growth rate of self-supplied fertilizers should be one of the main causes of the agricultural stagnation in the 1920's. This, however, calls for treatment in another paper[15].

IV-SUMMARY

In order to prove that the input level of fertilizer in the 1920's was not as high as that has been thought, we have tried to aggregate self-supplied and commercial fertilizer inputs of the period 1899–1929 into single input indices by the CES type of method of aggregation. First, the elasticity of substitution was estimated by assuming the equality between the

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[15] See footnote 5.

proportion of marginal productivities and the price rate of the two kinds of fertilizer. Next, the indices were constructed via two estimates and one assumed value (infinite) of this elasticity of substitution.

Some implications of the statistical findings can be suggested:

1. The regression results indicate that the elasticity of substitution between self-supplied and commercial fertilizers in prewar Japan was virtually lower than infinite and that the proportion of inorganic fertilizers to total fertilizers consumed tended to lower this elasticity in the period concerned.

2. In searching for the elasticity of substitution between self-supplied and commercial fertilizers, some biased technical progress which had the tendency of increasing commercial fertilizer consumption was also detected.

3. In contrast with a straight line presented by the index of infinite elasticity of substitution, the two newly constructed indices show fairly low growth rate after 1917. The two newly constructed indices of fertilizer input seem to better explain the long-term trends in yields of rice and agricultural products. These two also appear to substantially improve the results of AKINO-HAYAMI's previous work.

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