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FACTOR SUBSTITUTABILITY AND COMPLEMENTARITY IN AGRICULTURAL PRODUCTION

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I. Introduction

The intersectoral migration of resources plays a role in economic growth equally as important as technological change within individual industries.[1] However, the intersectoral resource migration basically depends upon the differential structure of its opportunity cost between industries, and the degree to which a resource will migrate against the difference of its opportunity cost and the amount of farm production that will be lost in the migration will depend upon the structure of factor relationships, that is, factor substitutability and complementarity in agriculture.[2] Despite such significance there have been little empirical analyses on this subject. In such an absence of empirical measurement, there have been two general notions in agricultural economics. The first is that one can dichotomize farm techniques into mechanical techniques which act exclusively as a labor substitute and biological techniques which act exclusively as a land substitute.[3] This notion has led us to the commonplace that an economy of small farm land area must pursue chemical-, not machinery-, intensive techniques in order to keep up with large farm land economies in farm production. However, Binswanger (1974) cast doubt on this notion, drawing on his

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[1] Salter (1960, pp. 147–55), for example, showed that half of the growth of productivity in England for the period 1924–1948 can be ascribed to the resources migration. With a more sophisticated econometric method Massell (1961) concluded that one-third of the growth of total productivity in U.S. for the period 1950–1956 was ascribed to the migration of resources.

[2] For recent empirical example, see Kako (1978), Ezaki (1979), and Lee (1980a).

[3] This idea is reviewed in a brief and compact fashion by Jurg, Janvry and Schmitz (1972): "Following Heady, a mechanical innovation essentially substitutes capital for labor but does not changes the physiological outcome of the plants and animals to which it may apply. According to Sen, investment in machinery like tractors, treshing machines etc. is useful mainly in replacing labor without changing yield per acre. Cline concludes that the evidence of a positive influence of machinery on yields is weak, and that tractor mechanization is much more likely to be purely labor-substituting. Hayami and Ruttan also dichotomized farm techniques into mechanical and biological techniques. Drawing on these notions, Jurg *et. al.* proposed to apply a 'two-stages production function' to farm production analyses."

empirical result that machinery was a good substitute for land in United States agriculture.

The second general notion is that the factor relationship remains unchanged. Obviously, however, there should be no *a priori* reason why the factor relationship remains unchanged over time. Hicks (1963) put forward a hypothesis with respect to this subject: the elasticity of substitution between labor and capital must fall as capital continues to grow when invention is almost wholly absent, but it will be high and will remain high when invention is very active. Sato and Hoffman (1968), Takayama (1974), and Zind (1979) provide empirical evidence that the elasticity of substitution between labor and capital has changed over time in the United States and Japan.

The well-known development of the translog production function by Christensen, Jorgenson and Lau(1973) opened the rigorous way to the empirical measurement of the factor relationship in the many-factor case. Using the translog production function approach, this paper investigates the internal structure of the factor relationship and its changes over time in Japanese agriculture. The results will be utilized to review the conventional notions as to farm technology and thus to gain a new insight into agricultural development issues.

II. Three Measures of the Factor Relationship: Theory

Three elasticities are estimated in this paper in order to gain an overall insight into the factor relationship in agricultural production: Allen Partial Elasticity of Substitution (AES), Hicks Partial Elasticity of Complementarity (HEC), and Direct Elasticity of Substitution (DES). Sato and Koizumi (1973) show that these measures are not exclusive but rather complementary to each other in exploring factor relationships, and that they can be estimated either from the production function or from the cost function. However, the cost function approach is justified only on the condition of equilibrium at cost minimization and "precise" measurement of the implicit factor prices. The production function approach, therefore, is taken in this paper.

Consider a production function:

$$(1) \qquad y = f(x_i, \ldots, x_n),$$

where y stands for output and x_i for the i-th factor input. We assume that f is well-behaved within a certain range. First, direct elasticity of substitution is measured from the production function as follows:

$$(2) \qquad D_{ij} = f_i f_j (x_i f_i + x_j f_j) / x_i x_j (2 f_{ij} f_i f_j - f_{ii} f_j^2 - f_{jj} f_i^2) \quad (i \neq j),$$

where $f_i = \partial f / \partial x_i$ and $f_{ij} = \partial^2 f / \partial x_i \partial x_j$. DES is thus a non-negative magnitude in the relevant range according to our well-behaved assumption. This measures the relative ease with which one factor can be substituted directly for another factor while maintaining output and other factor inputs constant.

The Allen partial elasticity of substitution can be measured from the production function with the following definition:

$$(3) \qquad \sigma_{ij} = (\sum_{k}^{n} x_k f_k / x_i x_j) \cdot F_{ij}/F \qquad (i.j = 1, \ldots, n),$$

where F is the bordered Hessian determinant of the production function and F_{ij} is the cofactor of f_{ij} in F. It registers the effect on the quantity demanded of one factor by a change in the price of another factor, holding output and other factor prices constant. Two factors, according to Allen (1938), are defined as substitutes or complements according as $\sigma_{ij} \gtrless$ o. It is deserving of attention that this AES reflects the overall relationship among factors, since, in measuring it, all factor quantities are allowed to vary together against a change in the price of one factor maintaining output constant with minimum cost.

Hicks partial elasticity of complementarity is the dual concept to AES, and is measured from the production function as follows:[4]

$$(4) \qquad c_{ij} = f_{ij} \sum_{k}^{n} x_k f_k / f_i f_j - (e - 1) \qquad (i,j = 1, \ldots n),$$

where e is the scale elasticity of the production function, and the term (e-1) is for excluding the scale effect in the case of a non-linear homogeneous production function. This measure registers the effect on the (shadow) price of one factor by a change in the quantity of another factor, holding marginal (shadow) cost and other factor quantities constant. We can interpret this measure as measuring the degree to which two factors jointly work to a change in output, since the measure involves the mixed derivative, f_{ij}. Hicks (1970), proposes to define the two factors as complements or substitutes according as $c_{ij} \gtrless 0$. We now have two different concepts of substitute and complement: in Allen's sense and in Hicks' sense. To avoid the apparent confusion, we call the two factors Allen-substitutes or Allen-complements according as $\sigma_{ij} \gtrless 0$, and Hicks-complements or Hicks-substitutes according as $c_{ij} \gtrless 0$.

Christensen, Jorgenson and Lau (1973) developed the translog production function which does not assume any arbitrary factor relationship. Thus, if the translog production function would be estimated, the three elasticities could be obtained without any *a priori* assumption as to factor relationship by substituting the first and second partial derivatives of the estimated function into the corresponding formulas, (2), (3), and (4).

[4] This was derived from a linear homogeneous production function by Sato and Koizumi (1973). A proof which does not rely on linear homogeneity is given by Lee (1980b).

III. Estimation of the Translog Production Function

3.1. Data

Farm records from the Survey of Rice Production Cost during the period 1955–1975 provide the data for this study. This survey, which has been conducted by the Ministry of Agriculture and Forestry of Japan (MAFJ), includes comprehensive information on all inputs, including the purchased and the self-supplied, for rice production on each farm. Sample farms for this survey are selected in the method of stratified random sampling from all over the country. Sample design is based on the results of the Census of Agriculture and Forestry and altered once every seven years or so in order to sustain the representativeness of the sample.

We selected four typical prefetcures among which very clear contrasts were observed in average farm land size per farm, farm wages and so on: Akita, Toyama, Aichi and Shimane prefectures. Akita and Toyama prefectures are well-known primary rice farming area with large size farms, while Aichi and Shimane prefectures are stagnant areas with small size farms. On the other hand, in Aichi and Toyama prefectures, affected heavily by adjoining industrial areas, part-time farming has remarkably advanced and farm wages have been very high compared with those in Akita and Shimane prefectures. Hence, we expect our data to envelop almost all varieties of rice farming techniques in Japan so as to represent the technological status of the country's rice farming.

About one-third to one-half of the farms surveyed by MAFJ were randomly reselected in each prefecture each year. This provided about thirty-five cases per prefecture each year, and the total sample size was 2,950 cases.

Output was measured in weight of brown rice. Input was categorized into four factors: land in cropped area (A); labor in adult-man-hours directly used for rice production (L); current goods, including fertilizer, pesticides and other materials in Yen (F); and machinery in terms of service flow in Yen (K). Machinery service consists of depreciation, interest on the value of machinery capital, fuel expenditure, sixty percent of custom work hired, and estimated expenditure on draft cattle service. Forty percent of custom work hired was divided by the wage rate in the same area, and then added to labor hours. All values were measured at 1970 constant prices, and all variables were transformed to geometric units for convenience.[5]

3.2. Estimation

The translog production function can be converted into factor share func-

[5] All our test results and the estimates of the elasticities of substitution and complementarity are independent of scaling (Berndt and Christensen 1973b).

tions provided that the production function is linear homogeneous and that the marginal value productivities of factor inputs are equal to their prices. Then the factor share functions can be used to estimate the coefficients of the production function. Such assumptions, however, are not always acceptable, especially when we use micro farm data. Hence, we estimated the translog production function directly from the data on inputs and output without converting into share functions.

For actual estimation, three years were set as one unit time, that is, the data period was segmented into seven time units in order to take into account irregular technological change explicitly, and then the following model was applied to the farm data to estimate the coefficients of the translog production function.

$$(5)\quad \ln y_f = \alpha_0 + \delta_r + z_t + \sum_{1}^{4} \alpha_i^t \ln x_{if} + \frac{1}{2} \sum_{i}^{4} \sum_{j}^{4} \beta_{ij} \ln x_{if} \ln x_{jf} + u_f,$$
$$(f = 1, \ldots, 2950, \quad r = 1, \ldots 4, \quad t = 1, \ldots, 7),$$

where $\beta_{ij} = \beta_{ji}$ and $\delta_1 = z_1 = 0$. In this specification f refers to sample farm, r refers to the prefecture which the f-th sample farm comes from, and t refers to the time unit which the f-th sample farm belongs to. Meanwhile α_i^t refers to the coefficient of the t-th time unit of α_i, and thus it reflects biases in technological change. The disturvance term u is assumed to follow the conventional OLS assumption. Simultaneous equations bias does not result, since input levels are assumed to be determined in terms of "anticipated", rather than realized, output in actual production.

If the production function is homogeneous, the following restrictions hold:

$$(6)\quad \sum_{j}^{4} \beta_{ij} = 0 \qquad\qquad (i = 1, \ldots, 4).$$

This function reduces to the Cobb-Douglas type, if the following additional restrictions are included:

$$(7)\quad \beta_{ij} = 0 \qquad\qquad (i \neq j),$$

If the scale elasticity is constant over time, the following restriction holds:

$$(8)\quad \sum_{i}^{4} \alpha_i^t = \sum_{i}^{4} \alpha_i^{t+1} \qquad\qquad t = 1, \ldots, 6.$$

Further, constant returns to scale imply that

$$(9)\quad \sum_{i}^{4} \alpha_i = 1$$

These restrictions are maintained as testable hypotheses as to functional specification.

OLS was applied to the estimation model (5), and a series of tests on functional specification was undertaken in order to choose the best specification. The change in the sum of the squared errors resulting from restrictions was calculated, and this change was divided by the sum of the squared errors of non-restricted regression. Then, both numerator and denominator of this ratio were divided by the appropriate number of degrees of freedom. The resulting statistics were taken as the F-value for the restrictions.

The validity of the homogeneity restrictions was accepted at a level of significance of 0.05, but the Cobb-Douglas type was rejected at a level of significance of 0.01. Also, restrictions of "constant scale elasticity" was accepted at a level of significance of 0.01, but the restriction of constant returns to scale was rejected at a level of significance of 0.01. According to these test results, homogeneity and "constant scale elasticity" restrictions were imposed on estimating the final coefficients of the production function.

However, the reciprocal summation of the Pearson correlation matrix for our data was 739.2; sampling variances of the OLS estimates would be expanded to about 15.2 times compared with the orthogonal case.[6] We thus concluded that OLS estimates suffered from serious multicollinearity and that the Ridge Regression method was preferable in this case.[7]

We modified the ridge regression estimator, which has been suggested by Hoerl and Kennard (1970), as follows in order to impose the restrictions stated above:[8]

$$\text{(10)} \qquad \hat{b} = \hat{\beta} + (X'X + KI)^{-1} R'[R(X'X + KI)^{-1} R']^{-1}(r - R\hat{\beta}),$$

where $\hat{\beta} = (X'X + KI)^{-1}X'Y$, and r stand for linear restrictions on the parameters β and $r = R\hat{\beta}$. Y is a vector of observations on the dependent variable, X is a matrix of regressors standardized in such a way that X'X is the non-singular correlation matrix, and k is a non-negative biasing factor. An increment of biasing factor (k) was terminated when the Vinod's Index of Stability of Relative Magnitude (ISRM) arrived at the minimum level (Vinod 1976): at $k = 0.10$ the ISRM was minimized while R-squares was reduced by only 0.042. Therefore, the estimates at $K = 0.10$ were adopted and the estimated coefficients are presented in Table 1.[9]

We investigated whether the estimated homogeneous translog produc-

[6] Sampling variances of the OLS estimates depend upon the latent roots of the Pearson correlation matrix (Johnston 1972, pp. 166–68).

[7] It has been proved by Hoerl and Kennard (1970), Theobald (1974) and others that ridge regression may produce improved estimates with smaller MSE than OLS. And many empirical studies have illustrated that ridge regression estimates are more stable despite revisions of observation and purturbations in data (Vinod 1978).

[8] As for restricted linear regression, see Johnston (1972), pp. 155–158.

[9] The OLS estimates are presented in the Appendix for reference. The result, however, produces negative output elasticities for labor and machinery. This unreasonable sign is likely due to serious multicollinearity as stated in the text.

TABLE 1 PARAMETER ESTIMATES OF THE HOMOGENEOUS TRANSLOG PRODUCTION FUNCTION

Parameters	Estimates	Parameters	Estimates
α_{11}	0.5782(0.0211)	α_{44}	0.0528(0.0166)
α_{12}	0.1325(0.0167)	α_{51}	0.4713(0.0221)
α_{13}	0.2093(0.0179)	α_{52}	0.2108(0.0225)
α_{14}	0.0655(0.0120)	α_{53}	0.2585(0.0196)
β_{11}	−0.0025(0.0078)	α_{54}	0.0447(0.0148)
β_{12}	0.0112(0.0058)	α_{61}	0.4662(0.0182)
β_{13}	−0.0204(0.0055)	α_{62}	0.1898(0.0171)
β_{14}	0.0116(0.0056)	α_{63}	0.2669(0.0170)
β_{22}	0.0108(0.0090)	α_{64}	0.0626(0.0122)
β_{23}	−0.0075(0.0062)	α_{71}	0.5339(0.0176)
β_{24}	−0.0146(0.0057)	α_{72}	0.1186(0.0131)
β_{33}	0.0104(0.0080)	α_{73}	0.2383(0.0162)
β_{34}	0.0175(0.0050)	α_{74}	0.0947(0.0117)
β_{44}	−0.0145(0.0065)	z_2	0.0153(0.0121)
α_{21}	0.5566(0.0199)	z_3	0.0206(0.0116)
α_{22}	0.1545(0.0181)	z_4	0.0127(0.0104)
α_{23}	0.2209(0.0172)	z_5	0.0570(0.0105)
α_{24}	0.0535(0.0139)	z_6	0.0013(0.0120)
α_{31}	0.5237(0.0225)	z_7	0.0512(0.0126)
α_{32}	0.1707(0.0208)	δ_2	0.1778(0.0092)
α_{33}	0.2153(0.0191)	δ_3	0.1145(0.0090)
α_{34}	0.0758(0.0178)	δ_4	0.0381(0.0094)
α_{41}	0.4951(0.0232)	α_0	−0.1137
α_{42}	0.2047(0.0228)	R-Squares	0.9105
α_{43}	0.2329(0.0209)	k	0.10

a. k is the biasing factor in the ridge regression
b. The figures in parentheses are standard errors.
c. δ_2 is for Akita, δ_3 for Toyama and δ_4 for Aichi prefecture respectively.

tion function was well-behaved. We found that the fitted output elasticities were positive for almost all observations, and that the bordered Hessian determinant was negative at almost all data points. Thus we concluded that the estimated production function was appropriate for representing the technological state of postwar Japanese agriculture.

IV. Empirical Results

4.1. Measured Factor Relationship in Postwar Japanese Agriculture

Three years moving averages of input quantities were applied to the formulas, and the estimated result is summarized in a diagrammatic form in Figure 1. Investigating DES, we find that the pairs land-machinery and current goods-machinery have the smallest DES, less than unity, as expected.[10]

Turning to the estimated AES, out of the six pairs, the pair machinery-current goods was the only one to show a complement relationship in Allen's sense: an increase in the price of current goods is to be associated with a decrease in the demand for machinery when output is maintained constant. What is to be noticed here particularly is that, to our surprise, machinery is a good substitute for land in Allen's sense. This point will be discussed further in the next section. A closer look shows that, as expected, land is substituted best by current goods when land prices rise, labor best by machinery when farm wages rise, current goods best by labor when current goods prices rise, and machinery best by labor when machinery prices rise.

Investigating the estimated HEC, we note that almost all of the factor pairs are complements of each other in Hicks' sense, that is, in the sense that an increase in one factor input is associated with an increase in the (shadow) price of the other factor when keeping the marginal (shadow) cost and other factor inputs constant. The pair machinery-labor is the only to be Hicks-substitute for each other. We now turn to investigating the degree to which each factor is complemented by other factors in the production process: land is complemented most by machinery when land input increases, labor most by land when labor input increases, current goods most by machinery when current goods input increases, and machinery most by current goods when machinery input increases. It is deserving of particular note that machinery and current goods are most important complements of each other.

What is to be noticed here is that the substitutability of machinery for the other factors initially exhibited a downward trend but then increased from the mid to late 1960s (Table 2).[11] This tendency coincides well with the fact that the modern rice farming machinery—powerful tractors, rice dryers, harvesting machines and transplanting machines—were developed and adopted by farmers from the mid to late 1960s. We

[10] However, it looks somewhat puzzling at first that labor and current goods are so substitutable directly as to have a DES greater than unity, This result may be ascribed to the fact that current goods includes herbicides which can effectively substitute directly for labor for weed control: According to a survey result, labor for weed control can be reduced to one-fifth by using herbicides as compared with the traditional method in rice farming. In addition, the type of fertilizer has been improved from bulky organic to concentrated mineral types, and further from bulky mono-nutrient to high-content fused types. Other chemicals have also transformed from powder or liquid to granular types, further from mono-element to composite types. These improved types always saved labor formixing and broadcasting, but these gains were usually absorbed by increases of their prices. This coexistence of various types of fertilizer and chemicals extended the direct substitutability between current goods and labor.

[11] Table 2 shows only AES for selected years. However, a similar tendency is observed in HEC or in DES.

TABLE 2 THE TREND OF THE ALLEN PARTIAL ELASTICITY OF SUBSTITUTION IN POSTWAR JAPANESE AGRICULTURE

Pairs	1955–1957	1958–1960	1961–1963	1964 1966	1967–1969	1970–1972	1973–1975
Land-Labor	0.868	0.884	0.881	0.900	0.899	0.874	0.780
–Current Goods	1.178	1.169	1.187	1.167	1.149	1.146	1.150
–Machinery	0.818	0.777	0.820	0.723	0.658	0.732	0.857
Labor-Current Goods	1.453	1.380	1.327	1.276	1.251	1.255	1.469
–Machinery	2.409	2.380	1.960	2.149	2.136	2.210	2.540
Current Goods –Machinery	−0.230	−0.288	0.016	−0.220	−0.205	0.109	0.305

a. Symmetric parts are omitted.
b. Calculated at the average inputs of the three consecutive years.

can infer from this coincidence that the substitutability of machinery for the other factors was extended by the modern rice farming machinery mentioned above.

4.2. The Long-Term Tendency

Our estimated results were compared with those of other authors (some of the latter were for prewar Japanese agriculture, some for the postwar and one was for United States agriculture) in order to investigate the long-term tendency of factor relationship. This comparison will show a contrast not only between prewar and postwar Japanese farm technology but also between traditional and modern farm technology. Unfortunately, however, this comparison had to be confined to the estimates for AES because there have been few estimates for the other elasticities. The summarized results are presented in Table 3.

AES between land and labor is positive but distinctly smaller than unity in any estimation without regard to period and country. This implies that land and labor are substitutable, but not so well, for each other in both periods and in both countries. Meanwhile, most of the estimates for AES between land and fertilizer are positive and larger than unity, that is to say, the two factors are good substitutes for each other. Considering the sensitive yield-response to fertilizer, we can take it as being plausible and expected.

As for the pair land-machinery, as mentioned in the previous section, our estimates indicate that the two factors are substitutes for each other. Kako (1978) also obtained the result that AES between the two factors was 0.361 in Japan in 1970. Abe's estimation (1978) for postwar Japanese agriculture also supports our result (positive AES between land and machinery). Furthermore, Binswanger (1974) reports that machinery is a better substitute for land than labor in United States agriculture. These re-

TABLE 3 COMPARISON OF THE ESTIMATES OF THE ALLEN PARTIAL ELASTICITY OF SUBSTITUTION

Author	Data			Model
	Nation	Period	Data	
Sawada	Japan	1883–1937	Time-series aggregated	CES
Shintani	〃	1890–1937	〃	Sato's CES
Le	〃	1903–1938	〃	Translog cost function
Abe	〃	1918–1935	〃	〃
Sawada	Japan	1953–1963	Time-series aggregated	CES
Kaneda	〃	1951–1960	Time-series average farm data of nine districts	〃
Abe	〃	1955–1975	Time-series aggregated	Translog cost function
Kako	〃	1953–1970	Time-series average farm data of three classes	〃
Lee	〃	1955–1975	Time-series cross-section farm data	Translog production function
Hasebe	〃	1975	Cross-section district averages	〃
Binswanger	U.S.	1947–1964	Time-series cross-section state data	Translog cost function

Author	Land-Labor	Land-Fertilizer	Land-Machinery	Labor-Fertilizer	Labor-Machinery	Fertilizer-Machinery
Sawada	0.586					
Shintani	0.347		−0.184		0.347	
Le	0.061	(−0.029)	−0.859	0.230	0.215	−3.945
Abe	0.583	1.137	(0.844)	−0.120	(−0.487)	−0.306
Sawada	0.397					
Kaneda[b]				0.7[c]	0.710	
Abe	(−0.235)	1.083	0.228	0.060	1.543	−8.000
Kako[b]	0.786	0.574	0.048	−0.207	0.934	−0.091
Lee[a,b]	0.869	1.164	0.769	1.344	2.280	−0.105
Hasebe	1.182		1.825		3.820	
Binswanger	0.204	2.987	1.215	−1.622	0.851	−0.672

Sources: Refer to corresponding author's paper in References

a. Pesticide and herbicide are included in fertilizer.

b. Averaged values.

c. Kaneda found that there was no large difference in the estimates of the AES between labor and capital whether he used gross-output data or value-added data. We can speculate from that result that the AES between labor and current goods would be very similar with the AES between labor and machinery (Berndt, 1973)

d. The parentheses denote the fact that these estimates differ remarkably from those of other authors.

sults contradict the conventional notion that machinery is exclusively labor-substituting.[12] However, Le (1979) and Shintani (1970) obtained the results that in prewar Japanese agriculture machinery was complementary to land. This contrast may imply a substantial difference in technological structure between prewar and postwar Japanese agriculture and/or between traditional and modern farm technology. In addition, such a land-machinery relationship may partly explain why larger size farms with high machinery density enjoy a higher yield than smaller farms with less machinery in postwar Japanese rice farming.

Labor and machinery have been substitutes for each other as expected. However, it is deserving of particular notice that the AES between the two factors was low in prewar Japan but has become near or greater than unity in postwar Japan and in the United States. This is another important difference between prewar and postwar Japanese and/or between traditional and modern farm technology.

Machinery and current goods have been complementary in both periods and in both countries, even if the estimated degrees are very different with the author. This point also casts doubt on the conventional notion that farm techniques can be dichotomized in mechanical and biochemical techniques, and that small farm land economy must pursue chemicals-intensive techniques. Finally, as for the AES between labor and current goods, the estimates vary so much with the author that we can not obtain any convincing idea from this comparison.

V. Summary and Conclusions

The factor relationship and its changes in agriculture were investigated in terms of three elasticities using the case of Japanese agriculture. The results and conclusions can be summarized as follows.

Current goods and machinery are so complementary as to be defined as complements in Allen's sense as well as in Hicks' sense. On the contrary, labor and machinery are so substitutable as to be defined as substitutes for each other in Hicks' sense as well as in Allen's sense. However, the direct substitutability between them is not so high (DES smaller than unity) because machinery input should be complemented by current goods.

The other four factor pairs were intermediate: substitutable to such a degree as to be defined as substitutes in Allen's sense, but complementary as to be defined as complements in Hicks' sense. However, the four factor pairs can be separated further into two groups: the pairs labor-current goods and land-current goods have an AES greater than unity (HEC

[12] The senses of substitutability and complementarity are somewhat obscure in the conventional notion. However, Allen's sense seems to almost correspond to the conventional, since Allen's sense is defined on an isoquant.

smaller than unity and DES greater than unity) while the other two pairs (landlabor and land-machinery) have an AES smaller than unity (HEC greater than unity and DES smaller than unity).

The substitutability between labor and machinery has been very high in postwar Japanese agriculture and, furthermore, has become higher from the late 1960s. Therefore, a change in farm wages has come to induce a great labor-machinery substitution and much greater substitution in the 1970s than in previous periods. Incidentally, machinery has been substitutable for land and has become more substitutable from the late 1960s. This extention of the substitutability between machinery and labor and land is ascribed to the development and diffusion of the modern rice farming machinery such as powerful tractors, rice dryers, harvesting and transplanting machines. The great substitutabilities between labor and machinery and between machinery and land have provided an important technological condition for a great many farm labor forces to migrate to the nonfarm sector without any shrinkage of farm production. In this sense, postwar Japanese farm technology has a relevance to other Asian countries aiming at high economic growth.

To gain an insight into the contrast between traditional and modern farm technology, our estimated results were compared with other authors' estimates for prewar Japanese agriculture. The role of machinery was limited only to labor-substitution in traditional agriculture. Furthermore, even the substitutability for labor was not so high: one should not overestimate the labor-substituting capacity of machinery in traditional agriculture. However, the role of machinery must be re-appreciated with reference to agricultural development issues in modern farm technology: machinery plays a critical role in substituting for farm labor on rising farm wages and also makes an important contribution to improving the land productivity. One thing to be noticed without fail incidentally is that machinery input must be complemented by current goods for the execution of these roles since current goods is the most important complement of machinery.

Finally, our empirical results illustrate that factor relationship changes over time, and, further, that Hicks' hypothesis with respect to changes in the elasticity of substitution—the elasticity will be high and will remain high when invention is very active—is valid in principle.

APPENDIX ORDINARY LEAST SQUARES ESTIMATES OF THE HOMOGENEOUS TRANSLOG PRODUCTION FUNCTION

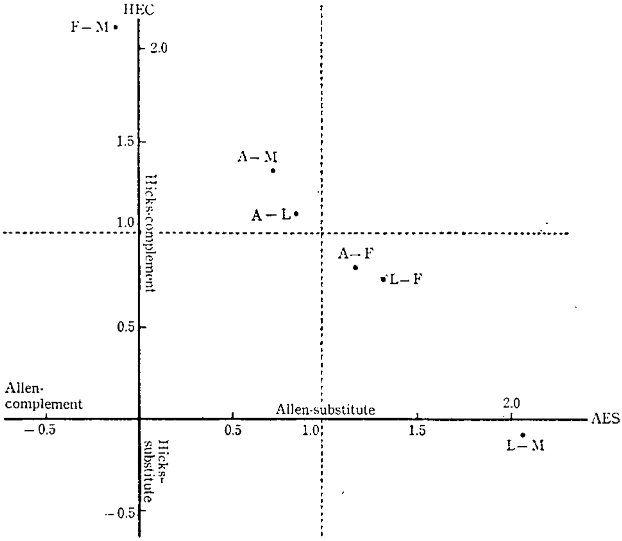
Parameter	Estimates	Parameter	Estimates
α_{11}	0.7748(0.0389)	α_{44}	0.0124(0.0157)
α_{12}	0.0880(0.0389)	α_{51}	0.6699(0.0331)
α_{13}	0.1735(0.0310)	α_{52}	0.1227(0.0288)
α_{14}	−0.0125(0.0225)	α_{53}	0.2226(0.0251)
β_{11}	−0.1649(0.0654)	α_{54}	0.0090(0.0152)
β_{12}	0.1857(0.0455)	α_{61}	0.7412(0.0380)
β_{13}	−0.0915(0.0395)	α_{62}	0.0800(0.0301)
β_{14}	0.0707(0.0251)	α_{63}	0.2079(0.0275)
β_{22}	−0.1166(0.0439)	α_{64}	−0.0051(0.0181)
β_{23}	−0.0236(0.0314)	α_{71}	0.8660(0.0412)
β_{24}	−0.0455(0.0199)	α_{72}	0.0113(0.0353)
β_{33}	0.1017(0.0431)	α_{73}	0.1301(0.0317)
β_{34}	0.0135(0.0183)	α_{74}	0.0165(0.0211)
β_{44}	0.0386(0.0157)	z_2	0.0786(0.0233)
α_{21}	0.8163(0.0361)	z_3	0.0689(0.0223)
α_{22}	0.0145(0.0338)	z_4	0.0656(0.0212)
α_{23}	0.2004(0.0284)	z_5	0.1272(0.0214)
α_{24}	−0.0073(0.0216)	z_6	0.0899(0.0227)
α_{31}	0.7547(0.0361)	z_7	0.1488(0.0243)
α_{32}	0.0392(0.0337)	δ_2	0.1725(0.0086)
α_{33}	0.2157(0.0268)	δ_3	0.0965(0.0087)
α_{34}	0.0143(0.0212)	δ_4	0.0267(0.0095)
α_{41}	0.7200(0.0355)	α_0	−0.1560
α_{42}	0.0858(0.0328)	R-Squares	0.9526
α_{43}	0.2057(0.0269)		

a. The figures in parentheses are standard errors.

b. δ_2 for Akita, δ_3 for Toyama, and δ_4 for Aichi prefecture respectively.

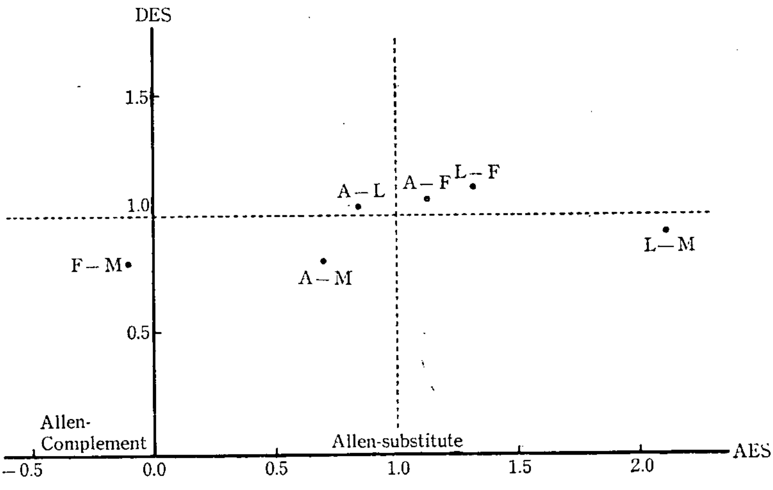
c. $\sum \beta_{ij} = 0$ and $\sum \alpha^t_i$ = constant.

FIGURE I–A Diagrammatic Summary of Factor Relationship (1)



Notes: A stands for land, L for labor, F for current goods, and M for machinery.

FIGURE I–B Diagrammatic Summary of Factor Relationship (2)



Notes: A stands for land, L for labor, F for current goods, and M for machinery.

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