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CHAPTER 8

A CES APPROACH TO THE MEASUREMENT OF INDUCED FACTOR AUGMENTATION: A TEST FOR JAPAN

Patrick Yeung and Terry L. Roe*

INTRODUCTION

The Hicksian version of the induced innovation hypothesis [8] focuses the cause of technological change on changes in relative input scarcities. The importance of this hypothesis lies in considering the source of technological change, not as exogenous, but as endogenous to the system within which this change takes place.

It is pointed out above, and thus we will not elaborate here, that the induced innovation hypothesis has been supported and expanded by some theorists and rejected by others. Among those who supported and expanded it are S. Ahmad[1], W. Fellner[2], C. Kennedy[3], and P. Samuelson[4] and J. Chipman[5]. The Kennedy growth model version was, however, rejected by W. Nordhaus.[6] In any event whether or not the hypothesis is worthy of credence depends substantially on its empirical verification.

The various attempts[7] at empirical verification of the hypothesis have also been discussed above. A shortcoming of these attempts is that they do not explicitly consider the mechanism which induces the biases. Also, they cannot consider the rate of technical change and its direction within the same model. To overcome this weakness, a more direct test of the induced innovation process is devised with Ahmad's framework. A factor augmenting CES production function is formulated so as to derive a direct test of the hypothesis that relative factor prices are a determinant of technical change biases.

The major objectives of this paper are to demonstrate this approach and to report the results from its application to the case of Japanese agriculture from 1880 to 1940. It is shown that contributions of the approach include estimating the rates of factor augmentation and revealing the possibility of a dynamic variable (or meta) elasticity of factor substitution. However, while the empirical results from fitting the model to Japanese data for the period 1880 to 1940 are consistent with technical change, they are not consistent with the simple version of the induced innovation mechanism postulated by Ahmad.

A CES-TYPE META-PRODUCTION FUNCTION

A dynamic two-factor production function of the general form

$$Y = F\ (K,\ L;\ t)$$

can be explicitly specified to be of the CES form:

$$(1)\qquad Y_t = [\alpha(K_t\ e^{\delta t})^{-\rho} + \beta(L_t\ e^{\lambda t})^{-\rho}]^{-1/\rho}$$

where Y, K, L and t represent output, capital, labor and time respectively; α and β are traditionally referred to as the distribution parameters, δ and λ the rates of factor augmentation over time, and ρ the substitution parameter.[8] A specific feature of this approach is that the factors are expressed in efficiency units.

There are, however, certain weaknesses implicit in this approach. First, the rates of factor augmentation are assumed to be fixed over time. There is no a priori reason why this should be true. Second, the model does not identify the sources of efficiency growth. Specifically, the question of whether the technological change indicated is induced or autonomous is ignored, the source of innovation being left unspecified.

To reduce these weaknesses, Equation (1) can be improved upon by postulating that the innovation is induced by relative input price changes which reflect changes in relative input scarcities. In dealing with agricultural output (Q), stipulating the primary factors to be land (A) and labor (L), a meta-production function may be written as

$$(2) \qquad Q_t = [\alpha(A_t\, e^{\delta I_t})^{-\rho} + \beta(L_t\, e^{\lambda I_t})^{-\rho}]^{-1/\rho}$$

where I_t represents an index of relative factor prices of labor and land. Like Equation (1) it is homogenous in the inputs. The essential difference between (2) and (1) lies in the replacement of time t with the labor-land index I_t. In this case, factor augmentation is assumed explicitly to be induced by changes in I_t. Even though constant factor-augmentation parameters, δ and λ, are still postulated, the rates of factor augmentation need not be constant over time.[9]

In both (1) and (2) it can be observed that if the factor augmentation coefficients are equal and different from zero, then technological change is neutral. When δ is different from λ the innovation is non-neutral in character. It is shown below that in (2) if the substitution parameter ρ and dI_t/dt are positive and δ exceeds λ, the case is land-saving (labor using) and if λ exceeds δ, the case is labor-saving (land using). If dI_t/dt is negative, then δ, λ must be negative inorder to be consistent with technical change. In this case, if $\delta > \lambda$ technical change is labor saving and if $\lambda > \delta$ technical change is land saving.

The mean estimates of δ and λ from a time series of observations on I_t reflect measured factor augmentation over a period of time. Thus, when making predictions based on these estimates, occasional reversed directional changes in I_t imply that previous efficiency gains are undone.

To make Equation (1) operational, let us define the relative factor price index to be

$$(3) \qquad I_t \equiv (w/r)_t/(w/r)_{t_o}$$

where $(w/r)_t$ is the relative prices of labor and land in the t-th year and t_o represents the base year.

Assuming that factors are paid according to their marginal productivities,

$$(4) \qquad r_t = \left(\frac{\partial Q}{\partial A}\right)_t = \alpha\left(\frac{Q}{A}\right)^{1+\rho} e^{-\delta\rho I_t}$$

and

$$(5) \qquad w_t = \left(\frac{\partial Q}{\partial L}\right)_t = \beta\left(\frac{Q}{L}\right)_t^{1+\rho} e^{-\lambda\rho I_t}$$

Dividing (5) by (4) yields:

$$(6) \qquad \left(\frac{w}{r}\right)_t = \frac{\beta}{\alpha}\left(\frac{A}{L}\right)_t^{1+\rho} e^{(\delta-\lambda)\rho I_t}$$

Taking logarithms and re-arranging terms,

$$(6a) \qquad \ln\left(\frac{A}{L}\right)_t = -\frac{1}{1+\rho}\ \ln\frac{\beta}{\alpha} + \frac{1}{1+\rho}\ln\left(\frac{w}{r}\right)_t + \frac{(\lambda-\delta)\rho}{1+\rho}\ I_t$$

from which we can obtain the elasticity of factor substitution σ_t,

$$(7) \qquad \sigma_t = \frac{d\ \ln\left(\frac{A}{L}\right)_t}{d\ \ln\left(\frac{w}{r}\right)_t} = \frac{1}{1+\rho} + \frac{(\lambda-\delta)\rho}{1+\rho}\ I_t = \frac{1}{1+\rho}\ [1 + (\lambda-\delta)\rho I_t].$$

This elasticity may not be constant over time. Assuming that $(\lambda-\delta) \neq 0$ and $\rho \neq 0$, σ would change as I_t changes. In this case, σ_t may be referred to as the "meta-elasticity of factor substitution" to associate it with the meta-production function. Note also that from the derivation $d\ \ln(A/L)/d\ \ln(w/r)$ of (6a), if I_t is taken as exogenously given, then σ_t equals the traditional form of $1/(1+\rho)$ in (7).

SOME VARIATIONS OF THE CES APPROACH

In model (1) factor augmentation is explicitly assumed to be induced by changes in I_t so that the rates of factor augmentation depend on the rate of change of I_t. Model (1) therefore considers factor price changes as the only inducement mechanism. It follows also that if I_t does not change over time, the rate of factor augmentation would become zero.

Additional variables can be specified to account for this shortcoming as follows:[10]

$$(8) \qquad Q_t = e^{\gamma t}[\alpha(A_t\, e^{\delta I_t})^{-\rho} + \beta(L_t\, e^{\lambda I_t})^{-\rho}]^{-1/\rho}$$

In this case, and in the absence of changes in I_t, time causes a neutral shift in the production function. The function can also be specified to allow for non-neutral shifts in technical change associated with the time variable as follows:

$$(9) \qquad Q_t = [\alpha(A_t\, e^{\delta I_t + \Theta t})^{-\rho} + \beta(L_t\, e^{\lambda I_t + \phi t})^{-\rho}]^{-1/\rho}$$

when $\Theta \neq \phi$, time causes a non-neutral shift of the production function at constant rates. Factor efficiency influences which are correlated with time might include advancements in the state of the basic sciences which affect the rate and the bias of the technological change. This does not imply a constant rate of efficiency gain because additional efficiency changes may be obtained through variations in I_t.

Production functions (2), (8), and (9) are homogeneous of degree one in A and L, implying constant returns to scale. If inputs other than A and L are considered in order to deal with the problem of variable returns to scale, (8), for instance, may be modified to include a scale parameter ν:

$$\text{(8a)} \qquad Q_t = e^{\gamma t}[\alpha(A\ e^{\delta I})^{-\rho} + \beta(L\ e^{\lambda I})^{-\rho}]^{-\nu/\rho},\ 0 \leq \nu \leq 1.$$

This is slightly more general than (8). Assuming that factors are paid according to their marginal productivities, the first derivatives, $\partial Q_t/\partial L_t$ and $\partial Q_t/\partial A_t$, of (8a) can be equated to w_t and r_t, respectively. Then dividing w_t by r_t yields

$$\left(\frac{w}{r}\right)_t = \frac{\beta}{\alpha}\left(\frac{A}{L}\right)_t^{1+\rho} e^{(\delta-\lambda)\rho I_t}$$

which is the same result as in (6). It follows that the elasticity of substitution of (8a) also has the same form as (7).

Proceeding similarly, the marginal productivity conditions of Equation (9) are

$$w_t = \frac{\partial Q_t}{\partial L_t} = \beta\left(\frac{Q}{L}\right)_t^{1+\rho} e^{-\rho(\lambda I_t+\phi t)}$$

and

$$r_t = \frac{\partial Q_t}{\partial L_t} = \alpha\left(\frac{Q}{A}\right)_t^{1+\rho} e^{-\rho(\delta I_t+\Theta t)}$$

yielding

$$(10) \qquad \left(\frac{w}{r}\right)_t = \frac{\beta}{\alpha}\left(\frac{A}{L}\right)_t^{1+\rho}\left(\frac{H_A}{H_L}\right)^{\rho}$$

where

$$H_A \equiv e^{\delta I_t + \Theta t}$$

and

$$H_L \equiv e^{\lambda I_t + \phi t}.$$

It can be seen from (10) that given the factor augmentation values, the sign of the substitution parameter ρ influences the direction of change in the land-labor ratio and thereby in the factor augmentation bias (see also appendix of chapter 2). Furthermore, since dI_t/dt can be positive or negative, the values of δ and λ must have the appropriate sign otherwise technical change is negative or undone. Following Drandakis and Phelps[11], the direction of Hicks' bias can be defined in terms of a change in the marginal rates of substitution at constant factor prices which yields the following three cases for (9).

(i) $\rho = 0$, technological change is always neutral;

(ii) $\rho > 0$, technological change is labor-saving if $\dot{h}_L > \dot{h}_A$ and land-saving if $\dot{h}_L < \dot{h}_A$;

(iii) $\rho < 0$, technological change is always labor-saving if $\dot{h}_L < \dot{h}_A$ and land-saving if $\dot{h}_L > \dot{h}_A$;

where

$$(11) \qquad \dot{h}_A \equiv d \ln H_A/dt = \delta dI_t/dt + \Theta,$$

$$\dot{h}_L \equiv d \ln H_L/dt = \lambda dI_t/dt + \phi.$$

When $\Theta = \phi$, it can be seen from these conditions that if dI_t/dt is positive, technical change is positive if δ, λ are positive. In this case, if $\dot{h}_L > \dot{h}_A$, $\delta < \lambda$ and the reverse if $\dot{h}_L < \dot{h}_A$. If dI_t/dt is negative then the factor augmentation parameters δ, λ must be negative in order to be consistent with technical change. In this case if $\dot{h}_L > \dot{h}_A$, $\delta > \lambda$, i.e., $|\delta| < |\lambda|$. The reverse exists if $\dot{h}_L < \dot{h}_A$.

It can also be verified that the elasticity of substitution derived from (10) takes the same form as that in models (2) and (8).

The above variations of (2) attempt to show the flexibility of the CES approach. Below, we briefly discuss the issue of hysteresis and its implication to the approach presented in this paper. This leads into the next section where estimation procedures are presented.

THE IDENTIFICATION OF HYSTERESIS

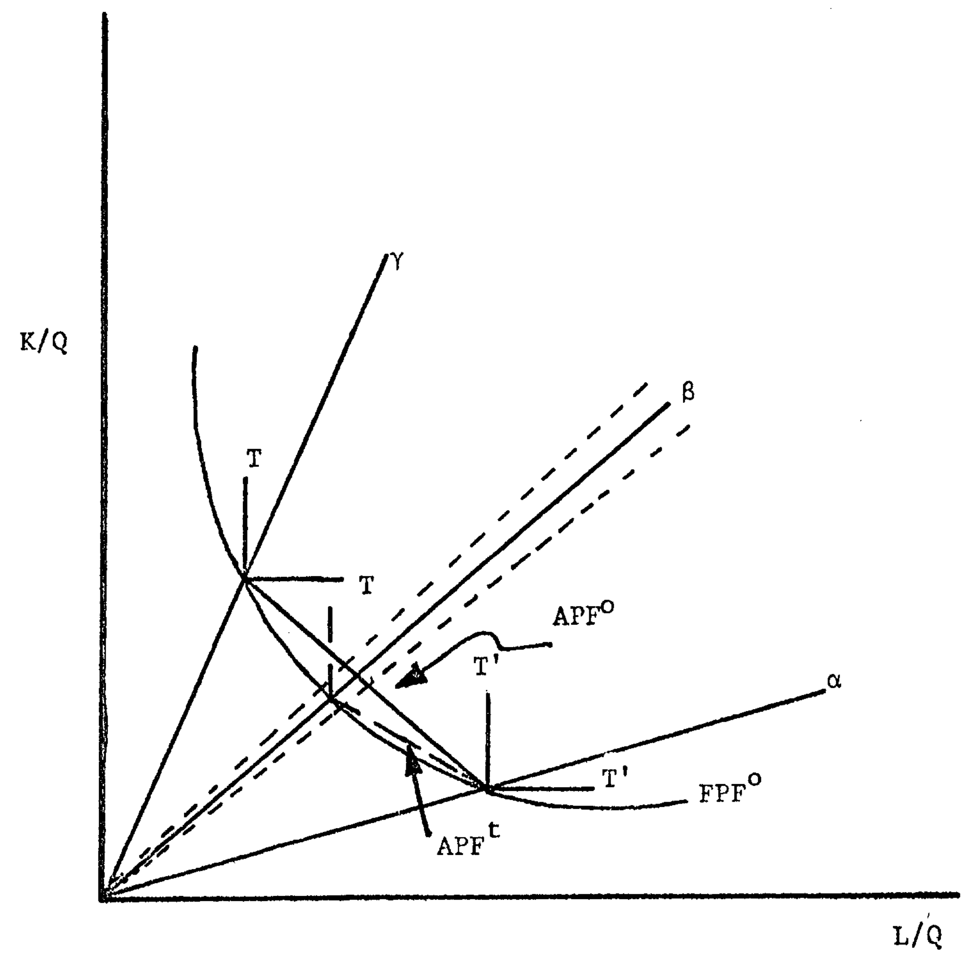
Hysteresis is the concept that biases of technical change continuing for some time in one direction would itself generate an inertia in the rate of bias in the same direction. The existence of hysteresis has certain implications to changes in the elasticity of factor substitution over time. Since the elasticity of substitution of the model presented here is dynamic, it is worthwhile to briefly consider the concept of hysteresis and to evaluate whether or not any empirical insights on this concept might be forthcoming from the estimation of our model.

The theoretical argument for the exhaustibility of technical change in one direction in Chapters III and IV above is an argument against hysteresis. In a recent work on technical change in nineteenth century America, Paul A. David[12] develops his own theory of induced innovation which incorporates the concept of hysteresis. The aspects of his theory which are of concern here are demonstrated in Figure I.

The discrete unit isoquants TT and T'T' represent two processes, with capital intensities γ and α, which have been adopted from an available process frontier (APF^{o}). The linear nature of the APF^{o} implies that the techniques TT and T'T' could be employed in linear combinations. The fundamental production frontier (FPF^{o}) represents the currently existing state of knowledge that poses some high profitability of technical success.

According to David, a substantial factor price change could induce changes in capital intensity in two ways. Given an initial

Figure 1



factor price tangency at the vertex of T'T' for example, a decrease in the relative price of capital could induce a movement on the APF^o toward the vertex of TT. Or, an alternative response, could be the development of a new technique at the upper vertex of APF^t with a capital intensity of β.[13]

With this background, David argues that a price disturbance which results in a movement from α to β -- "is clearly sufficient to launch an incidental, myopic exploration of the β ray."[14] He states that once the point of the β-ray's interesection with the upper vertex of APF^t is reached, a mere restoration of the status quo ante in the factor markets would not draw even the most myopic producer back to the α-technique.

The new variations of production methods generated by the experience with the β technique would, according to David, show a frequency distribution whose density is greatest in the region immediately surrounding the β ray, graphically suggesting the area between the dotted lines which are referred to as "elastic barriers". Technical progress now occurs as a movement down the β ray. He refers to this as localized technical progress due purely to "learning by doing" and is described as resembling the outcome of a random walk between the elastic barriers.[15] "Eventually, even with progress down the β-ray occurring at a retarded rate -- as we generally expect to happen on a learning curve -- the APF could become approximately L-shaped."[16]

An important implication of technical change occurring according to David's theory, is that the range of observed factor substitutions over time becomes less and less. In other words, the elasticity of factor substitution decreases over time as the APF becomes L-shaped. In any event, the range of observed factor substitutions would not increase. Our model would thus support the existence of hysterisis if σ_t decreases and not be consistent with hysterisis if σ is found to increase over time.

ESTIMATION PROCEDURES

Parameter estimates of the CES-type meta-production function developed above are derived from estimating the coefficients of their corresponding profit maximizing equations. These estimating equations and a discussion of the data used to estimate them are presented below.

Statistical Models

Model (2)

In principle, a test of the direction of bias in induced innovation may be obtained directly from Equation (6a). This is basically the Moroney method of estimating the elasticity of substitution. The statistical significance in the difference between λ and δ may be found by testing the statistical significance of the coefficient $(\lambda-\delta)p/(1+\rho)$ from zero in Equation (6a). This must be predicated on the prior test of singificance of ρ from the coefficients $1/(1+\rho)$ in the same equation. This procedure has been abandoned, however, because I_t is the index of $(w/r)_t$ so that a high degree of multicolinearity exists between $\ln(w/r)_t$ and I_t.

An alternative procedure is therefore used. The estimation of the unknown parameters of (2) is obtained by converting Equations (4) and (5) to ln form as follows:

$$(12) \qquad \ln\left(\frac{Q}{A}\right)_t = -\frac{1}{1+\rho}\ln\alpha + \frac{1}{1+\rho}\ln r_t + \frac{\delta\rho}{1+\rho} I_t$$

and

(13) $$\ln\left(\frac{Q}{L}\right)_t = -\frac{1}{1+\rho}\ln\beta + \frac{1}{1+\rho}\ln w_t + \frac{\lambda\rho}{1+\rho} I_t .$$

Since the coefficient $1/(1+\rho)$ is common to both variables r_t and w_t, these equations were combined to yield the following estimating equation

(14) $$Q' = X B + u$$

where

$$Q' = \begin{vmatrix} \ln (Q/A)_{t_o} \\ \cdot \\ \cdot \\ \cdot \\ \ln (Q/A)_{t_n} \\ \ln (Q/L)_{t_o} \\ \cdot \\ \cdot \\ \cdot \\ \ln (Q/L)_{t_n} \end{vmatrix} \qquad X = \begin{vmatrix} 1 & 0 & \ln & r_{t_o} & I_{t_o} & 0 \\ \cdot & \cdot & & \cdot & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot & \cdot \\ 1 & 0 & \ln & r_{t_n} & I_{t_n} & 0 \\ 0 & 1 & \ln & w_{t_o} & 0 & I_{t_o} \\ \cdot & \cdot & & \cdot & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot & \cdot \\ \cdot & \cdot & & \cdot & \cdot & \cdot \\ 0 & 1 & \ln & w_{t_n} & 0 & I_{t_n} \end{vmatrix}$$

$$B = \begin{vmatrix} b_1 \\ \cdot \\ \cdot \\ \cdot \\ b_5 \end{vmatrix} = \begin{vmatrix} -\frac{1}{1+\rho}\ln\alpha, & -\frac{1}{1+\rho}\ln\beta, & \frac{1}{1+\rho}, & \frac{\delta\rho}{1+\rho}, & \frac{\lambda\rho}{1+\rho} \end{vmatrix}'$$

and u is a 2n component vector of disturbances which are assumed to be randomly, log-normally and independently distributed with a zero mean and a constant variance. This formulation allows for the restricted estimation of $(1/1+\rho)$ by ordinary least squares and therefore the derivation of unique estimates of the parameters of (2).

Model (8)

From the first derivatives of Equation (8) with respect to A and L, the estimation equations of model (8) are

$$(15) \qquad \ln\left(\frac{Q}{A}\right)_t = -\frac{1}{1+\rho}\ln\alpha + \frac{1}{1+\rho}\ln r_t + \frac{\delta\rho}{1+\rho} I_t + \frac{\gamma\rho}{1+\rho} t$$

$$(16) \qquad \ln\left(\frac{Q}{L}\right)_t = -\frac{1}{1+\rho}\ln\beta + \frac{1}{1+\rho}\ln w_t + \frac{\lambda\rho}{1+\rho} I_t + \frac{\gamma\rho}{1+\rho} t$$

Since the coefficient $1/(1+\rho)$ is common to both the variables $\ln r_t$ and $\ln w_t$ in (15) and (16), and $\gamma\rho/(1+\rho)$ is common to the t-term in both equations, these equations can be combined in the manner of Equation (14) by constraining the coefficient of time to be equal in both equations as well.

Model (9)

From the first derivatives of Equation (9) with respect to A and L, the estimation equation of model (9) become:

$$(17) \qquad \ln\ (Q/A)_t = -\frac{1}{1+\rho}\ln\alpha + \frac{1}{1+\rho}\ln r_t + \frac{\delta\rho}{1+\rho} I_t + \frac{\Theta\rho}{1+\rho} t$$

and

$$(18) \qquad \ln\ (Q/L)_t = -\frac{1}{1+\rho}\ln\beta + \frac{1}{1+\rho}\ln w_t + \frac{\lambda\rho}{1+\rho} I_t + \frac{\phi\rho}{1+\rho} t.$$

Since the coefficient $1/(1+\rho)$ is common to both variables r_t and w_t, these equations can again be combined in the manner of Equation (14), but without constraining the time coefficient in the two equations to be equal.

In the case of Japan, it has been observed that for the period 1880 to 1940 Japanese agricultural production increased as wages generally declined relative to land values, i.e., dI_t/dt is generally negative. From (11) it therefore follows that the augmentation coefficients δ, λ should be equal to or less than zero to be consistent with technical progress. The induced innovation hypothesis of Ahmad[17] suggests that these circumstances should have encouraged technological progress which was biased in a land saving and labor using direction. The null hypothesis is that δ is not different from λ, i.e., that relative factor scarcity did not bias the direction of technical change. The alternative hypothesis is that δ is different from λ and to be consistent with a land saving and labor using direction of technical change, it follows from (11) that $\delta < \lambda$ where, as stated above, $\delta, \lambda \leq 0$. This test is predicated on the prior test that $\rho > 0$.

In the case of model (9), it is possible for the direction of technical change in Japan to have been labor saving even though the hypotheses that $\delta < \lambda$ and $\delta, \lambda \leq 0$ is accepted. This could occur if the augmentation coefficients associated with the time variable dominate the augmentation coefficients associated with I_t.

Data

Time series observations on agricultural output, land and labor inputs, their prices and a discussion of its derivation are available from Hayami and Ruttan[18] for Japan for the period 1880 to 1960. However, only the data for the period 1880 to 1940 were used because of data and structural discontinuities during the war and postwar periods.

All observations are quin-quennial. Observations on land and labor are measured at every five years beginning with 1880. Prices (rents and wages) are measured at the average of five years ending the year specified. This is to take into account the effect of expectation and adjustment lag on technological adoption.

The a priori selection of the "best" measures of agricultural output given in Hayami and Ruttan is difficult in the case of this model when various measures appear to contain a similar level of accuracy. Therefore, the two data series which are used as measures of agricultural output are gross agricultural output, net of intermediate goods supplied within agriculture, (all commodities) and gross output (all crops). The land area measure is hectares of arable land, while the measure for labor is agricultural male workers. Regarding measures of the dependent variable (Q') in (14) two transformations were therefore made. They are:

$$Q_1' = \begin{vmatrix} \ln \text{ (all commodities/arable land)} \\ \ln \text{ (all commodities/male workers)} \end{vmatrix}$$

$$Q_2' = \begin{vmatrix} \ln \text{ (all crops/arable land)} \\ \ln \text{ (all crops/male workers)} \end{vmatrix}$$

Land value is the weighted average of the prices of paddy fields and upland fields where the areas of each are used as weights. The specification of the functional form of the CES-type meta-production functions developed above offers a direct test of the Hicks-Ahmad version of the induced innovation hypothesis. In the next section, the results from fitting the above models to Japanese data for the period 1880 to 1940 are reported.

EMPIRICAL MODEL: THE CASE OF JAPANESE AGRICULTURE, 1880-1940

Initially, model (9) is fit to the Japanese data. The results of this model suggest that technical change in Japan is not consistent with the induced innovation hypothesis. In an attempt to alleviate some of the statistical shortcomings of this model, several of the other models specified above are also fit to the data. The results of these analyses are presented below.

Model (9)

The fit of the statistical model, which is derived by combining Equations (17) and (18) in the manner of Equation (14), appears to be reasonably good overall, although some serial correlation may be present (Table Ia). Small variance estimates and consistent signs were obtained for the coefficients of factor prices $1/(1+\rho)$, and for the coefficients of the wage-land index, I_t.

The parameter estimates of Model (9) and their respective variances are derived from the estimated statistical model (Table Ib). The derivation of the parameter estimates is straight forward. The estimated parameter variance is based on the large sample property relationships of the asymtotic distribution of a function of sample moments.[19]

The estimates of the distribution parameters α and β are of similar magnitude and relative variance. It follows from the relationship for estimating their variances that these estimates are sensitive to the magnitude and signs of intercepts b_1 and b_2.[20] Therefore, if the

TABLE Ia ESTIMATES OF EQUATIONS (17) AND (18) OF MODEL (9) WITH TWO DEPENDENT VARIABLE TRANSFORMATIONS

	Estimates of Coefficients								
Depend. Variable	b_1	b_2	b_3	b_4	b_5	b_6	b_7	R^2	d
Q_1'	-.21042	1.76609	.26683	-.01298	-.00248	-.07070	.00547	.990	1.202
	(.15089)	(.1451)	(.01587)	(.01365)	(.00155)	(.01315)	(.00120)		
Q_2'	-.22662	1.74260	.26790	-.00752	-.00534	-.06936	.00021	.982	.913
	(.18218)	(.17520)	(.01916)	(.01649)	(.00187)	(.01588)	(.00145)		

TABLE Ib PARAMETER ESTIMATES OF MODEL (9) BASED ON TWO ESTIMATIONS OF THE STATISTICAL MODEL

Depend. Variable	Estimates of Parameters						
	α	β	ρ	δ	Θ	λ	ϕ
Q'_1	2.20030	.00136	2.74771	-.01771	-.00338	-.09644	+.00746
	(1.14137)	(.00120	(.22287)	(.01837)	(.00206)	(.01876)	(.00156)
Q'_2	2.33810	.00151	2.73274	-.01028	-.00730	-.09474	+.00029
	(1.44732)	(.00163)	(.26696)	(.02230)	(.00241)	(.02266)	(.00193)

Var. $(\alpha,\beta) = e\ \exp.\ (-2b_j/b_3)\ (1/b_3^2)\ \text{Var. } b_3 + (b_j/b_3)^2\ \text{Var. } b_3 - (2b_j/b_3)\ \text{Cov. } b_jb_3$, for $j = 1,2$

Var. $\rho = (1/b_3^4)\ \text{Var. } b_3$

Var. $(\delta,\Theta,\lambda,\phi) = (1/1-b_3)^2\ (b_j/1-b_3)^2\ \text{Var. } b_3 + \text{Var. } b_j - (2b_j/1-b_3)\ \text{Cov. } b_jb_3$, for $j = 4,5,6,7$

assumptions which guarantee consistent estimates of the intercepts b_1 and b_2 are not strictly valid, the variances of α and β may be overestimated.

The estimates of the substitution and factor augmentation parameters are of primary importance here. The estimates of the substitution parameter ρ are positive, and strongly different from zero. Thus, except for the land augmentation parameter ϕ associated with time, all factor augmentation parameters are of the expected sign, i.e., their signs are consistent with technical change. The next step is to test the significant difference between the augmentation parameters to assess the direction of change.

To test the hypothesis of difference between the augmentation parameters of Table Ib, it is necessary to estimate their co-variances since only the co-variances of the coefficients of Table Ia are given directly.[21] The hypothesis that Θ is different from ϕ is accepted at the 95 percent level of confidence in the case of equation Q_1' but not in the case of equation Q_2'. Thus, based on the estimation of model (9), whether or not factors correlated with time alone have induced a labor saving (using) bias in the direction of technical change in Japan is indefinite.

While the parameters δ, λ are negative as expected, they do not appear to be of the expected relative magnitude, although the estimated variance of δ is relatively large. The test of the hypothesis that δ is not different from λ is rejected in both cases. This implies that $\delta > \lambda$, which is _not_ consistent with the Hicks-Ahmad version of the induced innovation hypothesis.

The rates of labor augmentation ($\dot{h}_L$) computed from Equation 11 exceed the rates of land augmentation ($\dot{h}_A$) for the entire period 1880-1940. Because of the magnitudes of Θ, the augmentation to land is slightly negative while $\dot{h}_L$ is positive except when wages increased substantially relative to the value of land. This occurred for the years 1920 and 1925. Labor augmented technical change was greater for the period 1880-1910 than for the period 1915-1940. We conclude that the results from fitting model (9) to the Japanese data therefore suggest that technical change occurred and that it was biased in the direction of saving labor and using land. This change occurred in spite of the fact that wages declined while land became relatively more scarce.[22]

The estimates of the elasticity of factor substitution obtained from model (9) are of particular interest in light of the theory of technical change advanced by David.[23] Estimates of the elasticity of substitution are obtained by substituting the estimates from Table Ib into Equation (7) for the years 1880-1890, 1880-1940, 1930-1940. These estimates appear in the left hand panel of Table III. These estimates range from a low of .2212 in 1880-90 to a high of .2338 in 1930-40. They suggest that the elasticity of substitution was constant with perhaps a slight tendency to increase. Given the estimates in Table Ib, it follows from Equation (7) that labor saving technical change induced by land prices increases relative to labor, the elasticity of substitution between land and labor would tend to increase.

These results appear to be inconsistent with the theory advanced by David which suggests that the elasticity of factor substitution should decrease as producers select a technique. As producers gain familiarity with the technique, technical progress is expected to occur so as to leave the factor intensity ratios unchanged even though changes occur in relative factor scarcity.

The results obtained from estimating model (9) appear to be consistent with the direction of technical change reported in the previous chapter but they are disappointing in that they are not consistent with the induced innovation hypothesis. That is, while the results indicate that $\dot{h}_L > \dot{h}_A$, we would have preferred that $\lambda \geq \delta$, λ, $\delta \leq 0$, and $\phi > \Theta$, ϕ, $\Theta > 0$ where their magnitudes are such that $\dot{h}_L > \dot{h}_A$. Thus, model (8) was estimated.

Model (8)

The results obtained from estimated model (8) yielded no appreciable change in the distribution parameters α, β, or the substitution parameter ρ. The estimates of δ are -.00165 and .0074 and are insignificantly different from zero in both equations Q_1' and Q_2'. The estimated magnitudes of λ are somewhat larger than in the case of model (9). The estimates of λ are -.10958 and -.10552 for equations Q_1' and Q_2' respectively and their corresponding variance estimates are small. The estimate of the augmentation parameter γ associated with time is .00461 and significant in the case of equation Q_1' but small and insignificant in the case of Q_2'.

As in the case of model (9) no definite statement can be made as to the neutral forces of technical change that are correlated with time. The estimates of the parameters δ, λ are significantly different and therefore $h_L > h_A$. This is consistent with a labor saving direction of technical change and inconsistent with the induced innovation hypothesis. While the elasticity estimates are somewhat smaller than in the case of model (9), they also show a tendency to increase over the period 1880-1940 (Table III).

Since the time variable is highly correlated with factor prices and since no definite statement can be made as to its impact on the rates of factor augmentation, it was removed and model (2) was estimated.

Model (2)

The results from fitting Model (2) to the data appear to be good with less evidence for serial correlation than in the previous models (Table II). Also, the coefficient estimates appear to be reasonably consistent with those obtained above (Table Ia), although, the estimates of the substitution parameter are generally somewhat larger. Thus, the estimates of the elasticity of factor substitution are generally somewhat smaller. The lowest estimates of σ_t for the years 1880-1890, 1880-1940 and 1930-1940 are .1541, .1645 and .1661 respectively (Table III). As in the case of the Model (9) this suggests that technical change did not increase the difficulty of substituting labor for land. The evidence here as in the previous cases may in fact suggest that the

TABLE II ESTIMATES OF EQUATION (14)(MODEL 2) WITH TWO DEPENDENT VARIABLE TRANSFORMATIONS

	Estimates of Coeffieients					Estimates of Parameters				
Depend. Variable	b_3	b_4	b_5	R^2	d	α	β	ρ	δ	λ
Q_1'	.30251	-.01169	-.08638	.921	1.082	11.0323	.00269	2.30571	-.01676	-.12384
	(.02241)	(.01915)	(.01861)			(11.3237)	(.00268)	(.24493)	(.02751)	(.02692)
Q_2'	.19864	-.00578	-.06478	.888	.831	.0644	.00002	4.03413	-.00721	-.08084
	(.02049)	(.01751)	(.01701)			(.1236)	(.00004)	(.51931)	(.02185)	(.02136)

a/ Estimates of b_1 and b_2 are not listed in order to conserve space.

TABLE III ELASTICITY OF FACTOR SUBSTITUTION ESTIMATES DERIVED FOR MODELS (9), (8) AND (2) FOR THE PERIODS 1880-1890, 1880-1940 AND 1930-1940

Depend. Variable	Model (9)			Model (8)			Model (2)		
	1880-90	1880-1940	1930-40	1880-90	1880-1940	1930-40	1880-90	1880 1940	1930 40
Q'_1	.2232	.2325	.2350	.1818	.1962	.1985	.2461	.2594	.2613
Q'_2	.2212	.2322	.2338	.1768	.1929	.1939	.1541	.1645	.1661

$$\sigma_t = \frac{1}{1+\rho} [1 + (\lambda - \delta)\ \rho I_\tau]$$

type of technical change experienced by Japan slightly increased the ease of substituting labor for land. As before, the hypothesis is accepted that δ is larger than λ (Table II).[24]

While Japanese land values generally increased relative to wages throughout the period 1880-1940, the period from about 1915 to 1940 is only intermitently characterized by this pheonomenon. That is, $dI_t/dt < 0$ for $t = 1880, \ldots, 1910$ and $dI_t/dt \gtrless 0$ for $t = 1915, \ldots, 1940$. This suggests that if no inertia in the direction of factor augmentation occurs both land and labor should be augmented during the latter period. Thus, the overall direction of factor bias for the latter period is difficult to predict on an a priori basis. Furthermore, if hysteresis is present, no increase in the elasticity of factor substitution can be expected.

Although the data series is perhaps too short for a supportable probability statement, the augmentation parameters of Model (2) were nevertheless estimated for these two periods (Table IV). The results for the period 1880-1910 are consistent with the results reported above, i.e., $\dot{h}_L > \dot{h}_A$. For the period 1915-1940, however, the direction of technical change appears to be nearly neutral. The estimates of the elasticity of factor substitution are consistent with those above and suggest that the ease of substituting labor for land may have increased (Table IV).

TABLE IV PARAMETER AND ELASTICITY OF FACTOR SUBSTITUTION ESTIMATES OF MODEL (2) WHERE I_t IS DIVIDED INTO TWO SERIES FOR $t = 1880, \ldots, 1910$ AND $t = 1915, \ldots, 1940$

Depend. Variable	$I_{1880}, \ldots, I_{1910}$		$I_{1915}, \ldots, I_{1940}$		$I_{1880}, \ldots, I_{1910}$	$I_{1915}, \ldots, I_{1940}$
	δ	λ	δ	λ	σ_t	σ_t
Q_1'	-.02503	-.12355>	-.02855	-.08061	.2154	.2373
	(.00917)	(.01075)	(.01235)	(.01363)		
Q_2'	.01173	-.09199>	-.02812	-.08583	.2034	.2263
	(.01140)	(.01152)	(.01283)	(.01210)		

CONCLUSION

A dynamic CES-type function is developed which incorporates the Hicksian induced innovation hypothesis into a meta-production function. Essentially, a relative input-price index is used as the shift variable of this function which is postulated within a two-dimensional input space. The addition of this variable results in the function having the desirable property of a variable elasticity of factor substitution. This study uses only a partial equilibrium approach in that changes in the relative price index are assumed to be exogenously determined.

Using historical data on Japanese agricultural production it is found that technological progress occurred which was labor saving and land using during the period 1880-1940. However, this bias appears to be stronger during the period 1880-1910 than during the period 1915-1940. This direction of technical change occurred in spite of the fact that wages generally declined while land increased in price. The results from fitting the above models to this data are therefore inconsistent with the Hicks-Ahmad version of the induced innovation hypothesis. These results suggest that some other fundamental mechanism was operating which saved labor relative to land even though labor was becoming less scarse relative to land. That is, we conclude that some other mechanism had a stronger influence on the direction of technical change than did the induced innovation mechanism.

Estimates of the elasticity of factor substitution for the period 1880-1940 ranged from a low of .1645 to a high of .2594. Changes in the elasticity of factor substitution over time were slightly positive, suggesting that the type of technical change which occurred did not increase the difficulty of substituting labor for land. This is not consistent with the mechanism of technical change postulated by Paul David.

There are two serious specification problems with our framework. First, our specification treats the prices of labor and land as exogenous when the price of land, at least, is almost totally endogenous to agriculture. This problem could easily cause statistical biases in our estimates of the augmentation parameters. Second, there are obviously more than two factors of production involved in the Japanese agricultural economy. The CES production function limitation of two factors of production, without making a separatiability assumption, prevents us from considering other inputs such as machinery. Since Japanese agricultural production during this period was labor intensive relative to American and European economies, the set of innovation possibilities facing the Japanese agricultural sector might have been dominated by simple mechanical innovations, especially since the initial part of this period is consistent with the adoption of agricultural machines in American and some European economies. These types of inputs might have been adopted and resulted in a substitution for labor, making the remaining labor more productive and using land. In this case, technical change could have been labor saving and the induced innovation mechanism would only have decreased the rate of adoption of mechanical technology. Our two factor model is not capable of capturing this adjustment.

FOOTNOTES

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[1] Syed Ahmad, "On the Theory of Induced Invention", Economic Journal, Vol. 76, June 1966, pp. 344-57.

[2] William Fellner, "Empirical Support for the Theory of Induced Innovation", Quarterly Journal of Economics, Vol. 85, No. 4, November 1971, pp. 580-604.

[3] Charles Kennedy, "Induced Bias in Innovation and the Theory of Distribution", Economic Journal, Vol. 74, No. 295, September 1964, pp. 541-47.

[4] Paul Samuelson, "A Theory of Induced Innovation along Kennedy-Weisacker Lines", Review of Economics and Statistics, Vol. 47, November 1965, November 1965, No. 4, pp. 343-56; and Rejoinder, Review of Economics and Statistics, Vol. 48, November 1966, No. 4, pp. 444-8.

[5] Johan S. Chipman, "Induced Technical Change and Patterns of International Trade" in Raymond Vernon (ied.), The Technology Factor in International Trade (New York: Columbia University Press, 1970), pp. 95-127.

[6] William D. Nordhaus, "Some Skeptical Thoughts on the Theory of Induced Innovation," Quarterly Journal of Economics, Vol. LSSSVII, No. 2, May 1973, pp. 203-219.

[7]Recent approaches employed to estimate the factor augmenting bias of technological change include Sato's, "The Estimation of Biased Technical Progress and the Production Function", International Economic Review, Vol. 11, June 1970, pp. 179-207; reformulation of the Hicksian mechanism of technological bias and Fellner's "Empirical Support" approach which more closely follows the Kennedy, "Induced Bias Innovation" version of the induced innovation mechanism. While their results are mutually supportive of a labor-saving bias in the U.S. non-farm sector, the nature of the mechanism inducing the bias is inconclusive. An approach along the lines of Ahmad and focusing more directly on the mechanism inducing technological change is followed by Hayami and Ruttan "Agricultural Development" where they consider a dynamic production function which they called a "meta-production function". See Chapter II for a discussion of these tests.

[8]For an application of this model, see Y. Kotowitz, "On the Estimation of a Non-Neutral CES-Production Function," Canadian Journal of Economics, Vol. 1, May 1968, pp. 429-39.

[9]They would not be constant over time if and when I_t is not perfectly correlated with time.

[10]Further modifications such as the specification of additional factor augmenting terms, the specification of I_t as a distributive lag or varying the degree of homogeneity can also be undertaken.

[11]E. Drandakis and E. Phelps, "A Model of Induced Invention, Growth and Distribution", Economic Journal, Vol. 76, pp. 823-840, Dec. 1966.

[12]Paul A. David, Labor Scarcity and the Problem of Technological Practice and Progress in Nineteenth Century America, Center for Research in Economic Growth, Memorandum No. 162, Stanford University, 1974.

[13]In an international context, according to David, the bias could also be caused by a foreign -- generated shift in FPF.

[14]Paul A. David, Labor Scarcity and ..., p. 81.

[15]As such, according to David, no theory of "inducements", no mechanism responsive to market signals needs to be found to explain the not infrequent appearance of extended innovation sequences.

[16]Paul A. Davis, Labor Scarcity and ..., p. 81.

[17]Syed Ahmad, "Theory of Induced Invention".

[18]Yujiro Hayami and Vernon W. Ruttan, Agricultural Development -- An International Perspective, Baltimore: John Hopkins, 1971.

[19]Henri Thiel, Principals of Econometrics, New York: John Wiley and Sons, Inc., 1971, pp. 373.

[20]The relationships for estimating the variances of these parameters appear in the footnote of Table II. It should be noted that each of these equations contain a remainder term which approaches zero as sample size increases.

[21]The estimates of the covariances of $\delta\lambda$ and $\Theta\phi$ are based on Thiel Principals of Econometrics and are of the form

$$\text{Cov. } \delta\lambda = \frac{b_6 b_4}{(1-b_3)^4} \text{ Var. } b_3 - \frac{b_6}{(1-b_3)^3} \text{ Cov. } b_4 b_3 - \frac{b_4}{(1-b_3)^3}$$

$$\text{Cov. } b_3 b_6 + \frac{1}{(1-b_3)^2} \text{ Cov. } b_4 b_6;$$

$$\text{Cov. } \Theta\phi = \frac{b_7 b_5}{(1-b_3)^4} \text{ Var. } b_3 - \frac{b_7}{(1-b_3)^3} \text{ Cov. } b_5 b_3 - \frac{b_5}{(1-b_3)^3}$$

$$\text{Cov. } b_3 b_7 + \frac{1}{(1-b_3)^2} \text{ Cov. } b_5 b_7.$$

[22]It is shown in the previous chapter that a general decline in the Japanese labor/land price ratio while the land/labor ratio increased is inconsistent with labor using technical change. Thus our conclusionson the direction of change appear to be in agreemant.

[23]Paul A. David, "Labor Scarcity".

[24]For purposes of comparison, Model (1) was estimated but it did not fit the data nearly as well as Model (2). Serial correlation appeared to exist and the variance estimates of the elasticity of factor

substitution $\left(\frac{1}{1+\rho}\right)$ were large. This precluded our tests of the augmentation parameters Θ, ϕ. The elasticity estimates ranged from 1.017 to -.0099 while the estimates of the time augmentation parameter of land ranged from .0116 to .0016. The estimate of the augmentation parameter for labor ranged from .0185 to .0144. The variance estimate of these parameters were also large.