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THE EFFECTS OF RESEARCH AND EXTENSION ACTIVITIES ON THE AGRICULTURAL TECHNOLOGY IN POSTWAR JAPAN : A MULTIPRODUCT COST FUNCTION APPROACH

YONG-SUN LEE*, **

Abstract

This study investigates the impacts of R&E activities on output bias as well as input biases of technical change in postwar Japanese agriculture. In an attempt to explain the rapid change in the relative price between crop and livestock products from the supply side, we calculate incremental or marginal cost elasticities of producing each product. We construct the required data set from four classes of farm size by adopting the Caves-Christensen-Diewert method and we then differentiate the pattern and magnitude of the impacts of R&E among these classes. To accomplish these objectives, we employ the framework of the restricted translog cost function which consists of two-output and four-variable and one-fixed input. To examine whether or not the multiproduct framework is preferable to the single product framework, weak separability of outputs and input nonjointness are tested.

I. Introduction

Technical change[1] has long been considered as a main source of

* Research Associate, Korea Rural Economic Institute, Seoul, Korea.
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1 The terms, technical change and technological change, are used interchangeably.

productivity change. As a major driving force of technical change, research and development activities have been emphasized in the literature. Along this line, early studies of productivity analysis in the agricultural sector have paid much attention in estimating the rate of return to agricultural research and/or extension (R&E) activities [e.g. Evenson and Pray (1991) and Ruttan(1982)]. Several studies have analyzed the rate and factor biases of technical change, in which time trend variables are used to represent the state of technology [e.g. Binswanger (1974), Kako (1978), Lee (1983), Antle (1984), and Kuroda (1989)].

Since technological knowledge as an outcome of R&E activities has a public good nature, especially in the agricultural sector, researchers have advocated that the government or public institution should play a leading role towards investing in R&E. In fact, it is widely known that, apart from Japan, the endeavor to enhance the current level of technology has been initiated and conducted substantially by the government or public institution in many other countries. R&E activities will bring about technological change, affect the farmer's production decision and the income distribution between different groups, and furthermore influence the rest of an economy (especially in a growing economy). In spite of its importance there are few studies that analyze explicitly the impacts of R&E activities on the direction and the magnitude of technical change.[2]

Kuroda (1988), using time trend as the technology measure, investigates the output bias of technical change between crop and livestock products and explains the quick drop of the price of livestock products relative to that of crop products in postwar Japan by the livestock-favoring bias of technical change. Huffman and Evenson (1989) estimate bias effects of technical change in U.S. crop products by utilizing direct measures of public and private research and extension services. More recently, Ito (1992) constructs R&E stock data in Japan by accumulating the expenditure for investment in R&E and estimates the effect of R&E stock on the rate of technical change.[3]

The study therefore investigates in detail the impacts of R&E

[2] For the importance of studying technical change biases in the agricultural sector, Lee(1983) summarizes well.

[3] Kuroda (1988) and Ito (1992) use unrestricted and restricted translog cost function, respectively, while Huffman and Evenson (1989) employ quadratic profit function.

activities on output bias as well as input biases of technical change in postwar Japanese agriculture. In an attempt to explain the rapid change in the relative price between crop and livestock products from the supply side, we calculate incremental or marginal cost elasticities of producing each product. We construct the required data set from four classes of farm size by adopting the Caves-Christensen-Diewert (1982) method and we then differentiate the pattern and magnitude of the impacts of R&E among these classes. In order to accomplish these objectives, we employ the framework of the restricted translog cost function which consists of two outputs and one-fixed and four-variable inputs. Moreover, the multiproduct function approach will enable us to examine the impacts of changes in output composition on the factor biases. To examine whether or not the multiproduct framework is preferable to the single product framework, weak separability of outputs and input nonjointness are tested.

The rest of this chapter is organized as follows. Section 2 presents the model. Section 3 reports the empirical implementation. Finally, Section 4 provides a brief summary and conclusion.

II. The Model

Consider the following restricted (or variable) cost function

$$C = G\,(Q, P, Z) \tag{2.1}$$

where Q is a vector of outputs, P denotes a vector of input prices, and Z is a vector of exogenous variables. Q is disaggregated into crop product (Q_G) and livestock product (Q_A). Z is a vector that consists of a fixed input (land), a R&E stock, dummy variables of farm sizes, and a weather condition (W).

For econometric analysis the following translog cost function is utilized.

$$\ln C = \alpha_0 + \sum_i^2 \alpha_i \ln Q_i + \sum_k^4 \beta_k \ln P_k + \sum_m^5 \beta_m \ln Z_m \tag{2.2}$$

$$+ \frac{1}{2}\sum_i^2 \sum_j^2 \gamma_{ij} \ln Q_i \ln Q_j + \frac{1}{2}\sum_k^4 \sum_l^4 \delta_{kl} \ln P_k \ln P_l + \frac{1}{2}\sum_i^2 \sum_k^4 \rho_{ik} \ln Q_i \ln P_k$$

$$+\frac{1}{2}\sum_{i}^{2}\sum_{m}^{5}\mu_{im}\ln Q_i \ln Z_m + \frac{1}{2}\sum_{k}^{4}\sum_{m}^{5}v_{km}\ln P_k \ln Z_m + \frac{1}{2}\sum_{m}^{5}\sum_{n}^{5}\phi_{mn}\ln Z_m \ln Z_n$$

$$+ \psi_w \ln W$$

where i, j are outputs (G and A); k, l denote inputs (L, M, I, and O); m, n are respectively land (B), R&E stock (R), and farm size dummies (D2, D3, and D4) of which each represents farm size of 0.5-1.0, 1.0-1.5, 1.5-2.0, and 2.0-hectare, respectively; and *ln* indicates the natural logarithm. Applying Shepherd's lemma to (2), we obtain factor demand functions. Assuming that farm firms take factor prices as given, the following cost share equations are derived from factor demand equations.

$$\frac{\partial \ln C}{\partial \ln P_k} = S_k = \beta_k + \sum_{l}^{4}\delta_{kl}\ln P_l + \sum_{i}^{2}\rho_{ik}\ln Q_i + \sum_{n}^{5}v_{kn}\ln Z_n \qquad (2.3)$$

where k=1,...,4. These share equations will be used for estimation purposes.

1. Bias Effects

In a multioutput and multifactor context, technical change can affect factor utilization and/or output composition differentially. The neutrality of technical change can be defined in two ways along the lines of Hicksian. One is the case of unchanging expansion path in the input space and the other is the case of unchanging expansion path in the output space.

Following Antle and Capalbo (1988), we define the following measures of biases.

Output Bias

In two-output case, a measure of output bias is defined by

$$B_{GA}^{Q} \equiv \partial \ln\left(\frac{\partial C}{\partial Q_G}\Big/\frac{\partial C}{\partial Q_A}\right)\Big/\partial \ln R \qquad (2.4)$$

$$= \partial \ln\left(\frac{\partial C}{\partial Q_G}\right)\Big/\partial \ln R - \partial \ln\left(\frac{\partial C}{\partial Q_A}\right)\Big/\partial \ln R$$

$$= \partial \ln MC_G / \partial \ln R - \partial \ln MC_A / \partial \ln R$$

B_{GA}^{Q} measures the rotation of the production possibility frontier, at a given point in the output space, due to technical change. Therefore technical change in the output space is defined as biased toward livestock products (toward crop products) if B_{GA}^{Q} is positive (negative) and neutral if B_{GA}^{Q} equals zero.

In order to derive the elasticity of marginal cost of each output with respect to R&E stock, we take the following steps. The cost-output elasticity of output *i*, ε_{CQi}, is firstly obtained:

$$\varepsilon_{CQi} = \frac{\partial \ln C}{\partial \ln Q_i} = \alpha_i + \sum_k^4 \rho_{ik} \ln P_k + \sum_i^2 \gamma_{ij} \ln Q_i + \sum_m^5 \mu_{im} \ln Z_m \quad (2.5)$$

The ε_{CQi} represents incremental or marginal cost of each output in percentage terms. Noting that $\partial \ln C / \partial \ln Q_i = \left(\frac{\partial C}{\partial Q_i}\right) / \left(\frac{C}{Q_i}\right) = MC_i / \left(\frac{C}{Q_i}\right)$, we differentiate the logarithm of ε_{CQi} with respect to the log of R&E stock holding outputs and factor prices constant. That is,

$$\frac{\partial \ln \left(MC_i / \left(C / Q_i \right) \right)}{\partial \ln R} = \partial \ln MC_i / \partial \ln R - \partial \ln C / \partial \ln R \quad (2.6)$$

Combination the above relation with $\partial \ln \varepsilon_{CQi} / \partial \ln R = \mu_{iR} / \varepsilon_{CQi}$ yields

$$\partial \ln MC_i / \partial \ln R = \mu_{iR} / \varepsilon_{CQi} + \partial \ln C / \partial \ln R$$

Input Biases

Binswanger (1974) proposed a single relative measure of bias in inputs using changes in factor cost shares. Antle and Capalbo (1988) extend Binswanger's definition of the bias measure to nonhomothetic and input-output nonseparable production technologies. According to their definition, the dual measure of input bias (B_k) contains two distinct effects: a scale effect owing to the movement along the nonlinear expansion path, and a (pure) bias effect owing to the shift in the expansion path (B_k^e). If the technology is homothetic, the scale effect is zero. In the multiproduct case, a measure of (pure) bias effect, i.e., a measure of the shift in the expansion path, can be defined as

$$B_k^e \equiv \partial \ln S_k(Q, P, Z) \Big/ \partial \ln R \mid_{dC=0} \tag{2.7}$$

$$= B_k - \left[\sum_i^2 \left(\partial \ln S_k(\cdot) \Big/ \partial \ln Q_i \right) \left(\partial \ln C \Big/ \partial \ln Q_i \right)^{-1} \right] \partial \ln C \Big/ \partial \ln R$$

where $B_k = \partial \ln S_k(\cdot) \Big/ \partial \ln R$.

2. Weak Separability and Nonjointness

This section deals with the important concepts for representing the structure of production, namely, weak separability of outputs and input nonjointness.

Weak Separability of Outputs

According to Hall (1973), a technology is weakly separable in outputs if and only if the cost function is written as

$$C(Q, P, Z) = G(h(Q), P, Z)$$

For our study, the separable restricted cost function is approximated by a Taylor series expansion of

$$\ln C(Q, P, Z) = \ln G(h(\ln Q), \ln P, \ln Z)$$

around the point Q_i=1, P_k=1 for all i, k. Then the approximate cost function can be shown to have the following relationship

$$\frac{\partial^2 \ln C}{\partial \ln P_k \, \partial \ln Q_G} \circ \frac{\partial \ln C}{\partial \ln Q_A} = \frac{\partial^2 \ln C}{\partial \ln P_k \, \partial \ln Q_A} \cdot \frac{\partial \ln C}{\partial \ln Q_G}$$

for all k=1.....4.

Writing a translog cost function like ours, weak separability requires that the parameters of the translog approximation satisfy the condition

$$\rho_{kG}\alpha_A = \rho_{kA}\alpha_G \tag{2.8}$$

simultaneously for all k=1,...,4.

Input Nonjointness

A technology is nonjoint in inputs (or nonjoint in production) if and only if the cost function is written as

$$C(Q, P, Z) = \sum_i G^i(Q_i, P, Z)$$

that is, the joint cost function is represented by the sum of independent cost function for each type of output. By so doing the approximate translog cost function becomes

$$\ln C(Q, P, Z) = \ln \sum_i G^i(\ln Q_i, \ln P, \ln Z)$$

Since the input nonjointness requires that the marginal cost of one output be independent of the level of the other output, the hypothesis of nonjointness may be examined by testing whether the relation

$$\gamma_{GA} = -\alpha_G \alpha_A \tag{2.9}$$

holds or not.

III. Empirical Analysis

The parameters of the variable cost function are estimated by applying multivariate regression methods on the joint cost equation (2.2), the cost share equations (2.3), and the revenue share equations (2.5). The revenue share equations are added to the regression since this provides an additional information to identify the coefficients of crop and livestock products.[4]

1. Estimation Procedure

The econometric versions of equations (2.2), (2.3), and (2.5) have been modified slightly. First, random disturbances were added to the restricted cost, cost share, and revenue share equations. These disturbances represent the effects of random weather conditions, approximation error and, optimization error. They are assumed homoscedastic and uncorrelated within each equation.

The translog cost function (2.2) may be viewed as a quadratic approximation to the true cost function, which implies that the symmetry conditions hold. Any sensible cost function satisfies linear homogeneity in factor prices. For the translog cost function defined in the previous section, this requires that

$$\sum_{k}^{4} \beta_k = 1 \text{ and}$$

$$\sum_{k}^{4} \delta_{kl} = \sum_{k}^{4} \rho_{k} = \sum_{k}^{4} v_{km} = 0$$

Using the price index of other inputs (Po) as a numeraire and imposing the restrictions of symmetry and linear homogeneity in factor prices, we estimate the system of equations. Based on the estimated parameters, coefficients of other inputs are obtained using the parameter restrictions.

Since outputs may be endogenously determined, an iterated three stage least square method is employed. The instrumental variables used for endogenous outputs are formed from the variables exogenous to the system: the real GDP, total number of population, dummy variables, and the lagged variables[5] of output prices, outputs, input prices, the R&E stock, and their cross terms.

2. The Data

The data used to estimate the model are the variable cost, the

[4] For a good explanation which includes the revenue share equations in estimation, consult, for example, Ray (1982) and Capalbo (1988).

[5] Since input decisions are believed to depend on the level of expected output, the lagged variables, as instruments, are employed instead of current variables, as used by Antle and Crissman (1986). Pindyck and Rotemberg (1983) and, Morrison (1988) find their most satisfactory results using lagged values of the exogenous variables.

quantities and revenue shares of crop and livestock production, the prices and cost shares of the variable factors of production (labor, machinery, intermediate inputs, and other inputs), and quantities of the fixed factor (land). The major sources of data are the Survey Report on Farm Household Economy and the Survey Report on Prices and Wages in Rural Villages (PWRV) published annually by the Ministry of Agriculture, Forestry, and Fisheries. In each year of 1960-87 period one average farm is taken from each of the four size classes: 0.5-1.0 (I), 1.0-1.5 (II), 1.5-2.0 (III), and 2.0 hectares or over (IV), from all Japan excluding the Hokkaido region because the latter region has the different size classification. The sample size is therefore 112.

The variable costs are defined as the sum of the expenditures on the four variable factor inputs. The quantity and price indexes of crop products were computed by the Caves-Christensen-Diewert (1982, C-C-D hereafter) method. Ten categories of crop products are distinguished with price indexes for these categories taken from the PWRV. The quantity index of livestock products is obtained by dividing the market sales of livestock products by the price index of livestock products taken from PWRV.

The quantity of labor is defined as the total number of male equivalent labor hours of operators, family, and hired workers. The number of male equivalent labor hours by female workers is estimated by multiplying the number of female labor hours by the ratio of female daily wage rate to male wage rate obtained from PWRV. The price of labor is obtained by dividing the wage bill for temporary hired labor by the number of male equivalent labor hours of temporary hired labor. The labor cost is defined as the sum of the labor cost of farm operators and family workers imputed by the price of labor (P_L) and the wage bill for hired labor.

The quantity and price indexes of machinery, intermediate inputs, and other inputs are also constructed by the C-C-D method. The cost of machinery is defined as the sum of the costs of machinery, energy, and rentals; the cost of intermediate inputs as the sum of the expenditure on fertilizer, feed, agrochemicals, materials, clothes, and others; and the cost of other inputs as the sum of the expenditures on animals, plants, and farm buildings and structures. The price data necessary for computing the C-C-D multilateral indexes are taken from PWRV.

The quantity of land is defined as total planted area which is composed of own and rented land. The cost share is obtained by dividing the expenditures on each category of factor inputs by the variable cost, while the revenue share follows from the division of market sales of each output by the variable cost. Finally, variable cost and the prices of the two products and three variable factor inputs are normalized by the price of other input.

As for the R&E stock, we employ the Ito (1992)'s estimate. According to Ito, first, the capital stock of research expenditures of the benchmark year (R_S) is obtained by applying the formula

$$R_S = E_{S\text{-}5}/(\delta_R + g)$$

where E is public research expenditures, δ_R is the rate of obsolescence of the stock of research expenditures. In deriving the above formula, the amounts of investment in research activities are assumed to be added to the stock with a six-year lag of development, while, in order to obtain R_S, 10 percent is applied for both δ_R and g. The R&E stock is then defined and calculated in such a way that the expenditure for extension activities is added to R_S, since extension activities are considered serving to form the capital stock of technological knowledge.

3. Empirical Results

The estimated parameters of the system and the associated asymptotic t-values are reported in (Table 1). The production structure is first tested in order to examine whether our model specification is valid or not.

Test Results of the Production Structure

The test statistics for hypotheses on the production structure are given in (Table 2). The weak separability of outputs is rejected at the 1% significance level. This implies that there could not exist consistent aggregation of combining crop products and livestock products to make a single index of aggregate output.

The null hypothesis of nonjointness in inputs is not rejected at the 1% level of significance but rejected at the 5% level. The result

TABLE 1 Estimated Coefficients of the Translog Restricted Cost Function

Parameter	Estimate	t-statistic	Parameter	Estimate	t-statistic
β_L	0.562	32.762	ν_{ID_3}	0.077	6.742
δ_{LL}	0.144	7,863	ν_{ID_4}	0.128	7.667
δ_{LM}	-0.024	-1.659	α_G	0.694	15.904
δ_{LI}	-0.090	-9.050	μ_{GB}	-0.359	-5.707
ν_{LB}	0.155	5.279	γ_{GG}	0.304	5.708
ρ_{GL}	-0.050	-2.511	γ_{GA}	-0.090	-9.843
ρ_{AL}	-0.076	-11.379	μ_{GR}	-0.109	-8.116
ν_{LR}	-0.089	-10.077	μ_{GD_2}	0.139	3.768
ν_{LD_2}	-0.023	-1.649	μ_{GD_3}	0.291	5.123
ν_{LD_3}	-0.055	-2.460	μ_{GD_4}	0.454	5.565
ν_{LD_4}	-0.111	-3.424	α_A	0.215	17.536
β_M	0.164	11.285	μ_{AB}	-0.086	-4.544
δ_{MM}	0.068	2.661	γ_{AA}	0.193	45.709
δ_{MI}	-0.091	-7.577	μ_{AR}	-0.028	-5.654
ν_{MB}	0.037	1.410	μ_{AD_2}	0.007	0.648
ρ_{AM}	0.006	0.356	μ_{AD_3}	0.024	1.495
ρ_{AM}	-0.026	-4.288	μ_{AD_4}	0.050	2.140
ν_{MR}	0.039	5.797	α_0	0.185	2.968
ν_{MD_2}	-0.010	-0.815	β_B	0.090	1.007
ν_{MD_3}	-0.012	-0.622	β_R	-0.103	-7.930
ν_{MD_4}	-0.010	-0.378	ϕ_{BB}	-0.058	-0.584
β_I	0.178	20.297	ϕ_{BB}	0.061	2.265
δ_{II}	0.215	21.779	ϕ_{BR}	0.037	1.020
ν_{IB}	-0.176	-11.294	Ψ_W	0.015	2.864
ρ_{GI}	0.034	3.509	β_{D_2}	-0.131	-2.610
ρ_{AI}	0.081	21.113	β_{D_3}	-0.271	-3.539
ν_{IR}	0.045	9.788	β_{D_4}	-0.461	-4.134
ν_{ID_2}	0.041	5.754			

Notes : G=crop, A=livestock, L=labor, M=machinery, I=intermediate input, B=land, R=R&E stock, and D2-D4 are farm size dummys. R-squared : cost function(0.98), labor share(0.87), machinery share(0.74), intermediates share(0.92), crop revenue share(0.90), and livestock revenue share(0.96).

TABLE 2 Tests of the Production Structure

Hypothesis	Wald Test Statistic	Degrees of Freedom	Critical Value 0.05	Critical Value 0.01
Weak Separability	386.82	3	7.81	11.3
Input Nonjointness	5.80	1	3.84	6.63

may thus be regarded as showing an evidence of input nonjointness, which means that there may not exist separate production function for each output.

Based on the parameter estimates in (Table 1), monotonicity and concavity conditions are checked at each observation. Since all the estimated shares for both outputs and inputs are positive, the production technology satisfies monotonicity condition. Though concavity condition with respect to factor prices is not met over some observations of the data set[6], the convexity with respect to outputs are satisfied at all sample points.[7]

Estimation Results

The estimated parameters given in (Table 1) may be utilized for further analysis.[8] (Table 3) summarizes incremental or marginal cost elasticity of producing each output and cost elasticity with respect to R&E stock. They are presented in the form of averages for each class of farm sizes. As the incremental or marginal cost elasticity of each

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[6] One of the eigenvalues of the Hessian matrix is positive, while the others are negatives.

[7] Nontheless the estimated cost function may still represent a second order approximation to the true data generating cost function which satisfy curvature conditions. See, for example, Mckay et al. (1983) and Antle and Capalbo (1988).

[8] I also estimated with some variants of the econometric specification which impose concavity restriction and/or include no size dummy variables to reduce the number of parameters. However, no critical differences were found in terms of qualitative implication. The results are not displayed here to save space. (The estimation results of the case of no size dummys may be referred to Lee (1995)).

TABLE 3 Cost-output Elasticities and Cost-R&E Elasticities

Fram Size	$\varepsilon_{C_{QG}}$	$\varepsilon_{C_{QA}}$	ε_{CR}
Ⅰ	0.766	0.235	-0.027
Ⅱ	0.853	0.236	-0.095
Ⅲ	0.968	0.260	-0.129
Ⅳ	1.046	0.260	-0.172
Average	0.908	0.239	-0.106

Notes : I(0.5-1.0), II(1.0-1.5), III(1.5-2.0), and IV(2.0-hectare). $\varepsilon_{CQi} \equiv {}^{\partial \ln C}/_{\partial \ln Q_i}$, $i = G, A$ and $\varepsilon_{CR} \equiv {}^{\partial \ln C}/_{\partial \ln R}$.

output may be used as a partial measure of scale economy, the figures in the first and second columns of (Table 3) exhibit that larger scale economy exists in livestock production than in crop production. The cost elasticity with respect to R&E gives the cost reduction effect due to changes in R&E stock. The estimates in the last column of (Table 3) demonstrate that the larger the farm size is, the greater the effect of cost reduction. This implies that the investment in R&E activities carried out by the government or public institution has significantly enhanced the productivity of the larger farm.

(Table 4) presents the estimates of the elasticity of marginal cost of each output with respect to R&E stock as well as the output bias of technical change attributed to the increase in R&E stock. The magnitudes of the estimated parameters seem to indicate that output bias effects are marginal for all classes of farm size. Though the magnitudes of bias effect are small, the signs of the estimates indicate that the additional R&E has some impact on farmer's production decision in such a way that it favors crop product in smaller farm while it favors livestock product for larger farm.

In (Table 5) the Hicksian bias measures of factor inputs and their decompositions into each contributor are presented. These Hicksian measures of input biases demonstrate that additional R&E during the 1960-87 period had a bias effect against labor usage and toward machinery usage, intermediate inputs usage, and other inputs

TABLE 4 The Output Bias Measure

Farm Size	*MCGR*	*MCAR*	B^Q_{GA}
I	-0.171	-0.150	-0.021
II	-0.223	-0.217	-0.006
III	-0.242	-0.256	0.014
IV	-0.278	-0.295	0.017
Average	-0.229	-0.230	0.001

Notes : I(0.5-1.0), II(1.0-1.5), III(1.5-2.0), and IV(2.0-hectare).
$MCGR = \partial \ln MC_G / \partial \ln R$, $MCAR \equiv \partial \ln MC_A / \partial \ln R$, and
$B^Q_{GA} = MCGR - MCAR$.

TABLE 5 Factor Biases and Their Decopmositions

	B_i	B^s_{iG}	B^s_{iA}	B^e_i
Labor	-0.18	-0.01	-0.07	-0.26
	(68.7)	(4.5)	(26.8)	(100.0)
Machinery	0.26	0.00	-0.07	0.19
	(135.6)	(2.3)	(-37.9)	(100.0)
Intermediate	0.19	0.02	0.15	0.35
inputs	(53.2)	(4.4)	(42.4)	(100.0)
Other inputs	0.06	0.01	0.11	0.18
	(32.2)	(7.1)	(60.7)	(100.0)

Notes : B_i is the total cost share change dut to technical change; B^s_{iG} and B^s_{iA} are scale effects, and $B^e_i = B_i + B^s_{iG} + B^s_{iA}$ is the Hicksian bias. Figures in parentheses indicate percentage contributions.

using technology. To a large extent, these Hicksian biases are explained by shifts in the expansion path. Interestingly, while most of the scale effects come from livestock production in factor inputs, the scale effects explained by crop production are negligible. The scale effect due to livestock production exhibits against labor and machinery inputs and strongly toward intermediate inputs (including feed as an important item) and other inputs (of which animals and buildings and structures are the main items). This result corresponds to Kuroda (1988)'s finding that the rapid exit of labor from agriculture in postwar Japan owes much to the rapid expansion of livestock production.

IV. Summary and Conclusions

This study has investigated explicitly the output bias as well as input biases of technical change which are considered to be caused by public research and extension activities in postwar Japanese agriculture. A restricted translog cost function with multiple outputs is specified and estimated for the 1960-87 period. R&E stock data and data from four classes of farm size for all Japan excluding Hokkaido region are utilized in the estimation procedure.

The major findings of the study are as follows. Public R&E caused small output bias effect in favor of crop product for the smaller farm whereas it brought bias effect slightly toward livestock product for the larger farm. However, overall, no significant evidence is found that public R&E activities has changed the output composition of Japanese farms during the sample period. Our results, therefore, do not seem to support the hypothesis suggested by Kuroda (1988) that the rapid decrease in relative price of livestock product is due to the bias of technical change which favors livestock production. Rather, our finding tends to suggest that the dramatic increases in livestock production, accompanied by economies of scale in the production process, have decreased the price of livestock so drastically.[9]

[9] In order to measure how much change in relative price between crop and livestock products has been caused by R&E, it is necessary to incorporate demand condition of each product into the analysis. However, considering the demand of livestock product has experienced much greater increase in postwar Japan than crop product, it leads us to suggest this.

For inputs, public R&E has had quite a considerable impact on the decision of allocating Japanese farm factor resources. It caused (relative) bias effects against labor input but in favor of machinery, intermediate, and other inputs usage. The direction of the biases in factor inputs is consistent with the induced innovation hypothesis.

Rejection of weak separability of outputs and input nonjointness implies that the multiproduct function approach is preferable when analyzing the agricultural technology of postwar Japan.

REFERENCES

Antle, J.M. 1984. "The Structure of U.S. Agricultural Technology, 1910-1978" *American Journal of Agricultural Economics* 66, 414-21.

Antle, J.M. and S.M. Capalbo. 1988. "An introduction to Recent Developments in Production Theory and Productivity Measurement," *Agricultural Productivity: Measurement and Explanation*, ed. S.M. Capalbo and Antle, J.M., Washington DC: Resources for the Future.

Antle, J.M. and C.C. Crissman. 1986. "The Market for Innovations and Short-Run Technological Change: Evidence from Egypt," *Economic Development and Cultural Change* 34, 669-90.

Ball, V.E. 1988. "Modeling Supply Response in a Multiproduct Framework," *American Journal of Agricultural Economics* 70, 813-25.

Binswanger, H.P. 1974. "The Measurement of Technical Change Biases with Many Factors of Production," *American Economic Review* 64, 964-76.

Caves, D.W., L.R. Christensen, and W.E. Diewert. 1982. "Multilateral Comparison of Output, Input, and Productivity Using Superlative Index Numbers," *Economic Journal* 92, 73-86.

Capalbo, S.M. 1988. "A Comparison of Econometric Models of U.S. Agricultural Productivity and Aggregate Technology," *Agricultural Productivity: Measurement and Explanation*, ed. S.M. Capalbo and Antle, J.M., Washington DC: Resources for the Future.

Evenson, R.E. and C.E. Pray. 1991. *Research and Productivity in Asian Agriculture* (Cornell University Press, Itaca and London).

Hall, R.E. 1973. "The Specification of Technology with Several Kinds of Outputs," *Journal of Political Economy* 81, 878-92.

Huffman, W.E. and R.E. Evenson. 1989. "Supply and Demand Functions for Multiproduct U.S. Cash Grain Farms: Biases Caused by Research and Other Policies," *American Journal of Agricultural Economics* 71, 761-73.

Ito, J. 1992. "An Economic Analysis of Investment in Agricultural Research and Extension Activities in Japan," *Keizai Kenkyu* in Japanese) 43, 237-47.

Kako, T. 1978. "Decomposition Analysis of Derived Demand for Factor Inputs," *American Journal of Agricultural Economics* 60, 628-35.

Kuroda, Y. 1988. "The Output Bias of Technological Change in Postwar Japanese Agriculture," *American Journal of Agricultural Economics* 70, 663-73.

________. 1989. "Impacts of Economies of Scale and Technological Change on Agricultural Productivity in *Japan,*" *Journal of the Japanese and International Economies* 3, 145-73.

Lee, J.H. 1983. "The Measurment and Sources of Technological Change Biases, with an Application to Postwar Japanese Agriculture," *Economica* 50, 159-73.

Lee, Y.S. 1995. Empirical Studies on Economic Development and Technical Change, Unpublished Ph. D. Thesis, University of Tsukuba.

Mckay, L., D. Lawrence, and C. Vlastuin. 1983. "Profit, Output Supply, and Input Demand Functions for Multiproduct Firms: The Case of Australian Agriculture," *International Economic Review* 24, 323-39.

Morrison, C.J. 1988. "Quasi-Fixed Inputs in U.S. and Japanese Manufacturing: A Generalized Leontief Restricted Cost Function Approcah," *Review of Economics and Statistics* 70, 275-87.

Pindyck, R.S. and J.J. Rotemberg. 1983. "Dynamic Factor Demands, Energy Use and the Effects of Energy Price Shocks," *American Economic Review* 73, 1066-79.

Ray, S.C. 1982. "A Translog Cost Function Analysis of U.S. Agriculture, 1933-1977," *American Journal of Agricultural Economics* 64, 490-98.

Ruttan, V.W. 1982. *Agricultural Research Policy* (University of Minnesota Press, Minneapolis).