「経営学論集」, 第18巻 第4号, 75-112, 2008
KYUSHU SANGYO UNIVERSITY, *KEIEIGAKU RONSHU* (*BUSINESS REVIEW*) Vol. 18, NO. 4, 75-112, 2008

〔論 説〕

Effects of R&E Activities on Rice Production in Taiwan, 1976-93: Revised*

Yoshimi Kuroda
Faculty of Management

January 7, 2008

Abstract

Using the translog variable cost function framework, this paper investigates quantitatively the impacts of the public R&E activities on the production structure of the Taiwanese rice industry for the 1976-93 period. It was found that the R&E activities by the government have played an important role in raising the productivity in the Taiwanese rice sector since the mid-1970s. Furthermore, technological change due to the public R&E activities has been biased toward saving labor, and using intemediate inputs and capital. These biases have been consistent with the changes in the relative prices of these factor inputs, i.e., saving a relatively more expensive factor input (labor) and using relatively less expensive factor inputs (intermediate inputs and capital). In this sense, the public R&E activities have been sensitive to the price signal of the factor markets. This finding is consistent with the Hicksian induced innovation theory.

Keyword: R&D, Agricultural Technology, Agricultural Extension Services, Variable Cost Function, Factor Allocation, Taiwan Rice Sector

JEL Classification Numbers: 03 (Technological Change)

---

*This paper is a revised version of "Effects of R&E Activities on Rice Production in Taiwan, 1976-93" published in *Taiwanese Agricultural Economic Review*, Volume 3, Number 1,1997 (pp. 96-145). The author appreciates constructive and helpful comments on the earlier version of this paper by Drs. Shenggen Fan and Philip G. Pardey at the International Food Policy Research Institute (IFPRI), Dr. Junichi Ito at the National Research Institute of Agricultural Economics in Japan, Professors Naziruddin Abdullah, J.M. Alston, D.S. Guo, S. Ito, T. Kako, J.K. Park, and E. Wailes. He also thanks Dr. Lailani L. Alcantara for her careful editing of English of this paper. This work was partially funded by a Grant-in-Aid for Scientific Research (C) No.06660273 from the Ministry of Education, Science, Sports and Culture of Japan (MESSC), the Nomura Foundation for Social Sciences, the Japan Securities Scholarship Foundation, the Murata Science Foundation, and the Statistical Data Bank Project of the MESSC. However, the opinions expressed are those of the author alone.

1 Introduction

In Taiwan, it was found that despite the total production of rice has declined drastically due mainly to a rapid decrease in the planted area for rice since the mid-1970s, the rice production has shown fairly high rates of technological progress. As shown in Figure 5, the rate of technological change increased steadily from about 0.5 percent per annum in 1976 to about 3.5 percent per annum in 1990, and it maintained at the latter level in the early 1990s (Kuroda 1996). This suggests that the rice sector in Taiwan has shown a good performance in the development and diffusion of new technologies since the mid-1970s.

In general, new technology in agriculture is generated by the *R&D* efforts of the public and private organizations, and by the efforts of farmers themselves. Nevertheless, the public research and extension (*R&E* hereafter) activities are overwhelmingly important in generating new technologies for agriculture in many countries (Hayami and Ruttan 1985).

Bearing this in mind, the first objective of this paper is to investigate the effects of the public *R&E* activities on the extent of technological progress in the Taiwanese rice sector for the 1976-93 period.

It was found that the bias of technological change (which has been labor-saving, intermediate-inputs-using, and capital-using) in the Taiwanese rice production during the 1976-93 period is consistent with the Hicksian (1963) induced innovation hypothesis (Kuroda 1996). However, this result is based on the translog variable cost function model where time trend is used as an index of technological change. The present study employs a more direct proxy variable for the index of technological change, i.e., the stock of technological knowledge measured in the capital stock of public *R&E* expenditures (or investments).

In relation to the first objective, the second objective of this study is to examine whether or not the bias due to public *R&E* activities has been consistent with the Hicksian induced innovation hypothesis in the Taiwanese rice production. This examination is tantamount to investigating whether or not the public *R&E* activities in the Taiwanese rice sector have been sensitive to the movement of the agricultural factor markets. This area of research is still relatively new in the context of Taiwanese agriculture and is therefore expected to offer not only a better understanding of technological change in Taiwanese agriculture, but also information for policy makers to organize better public *R&E* activities for Taiwanese agriculture.

It is also noted that many studies have been undertaken in a number of countries which support the proposition of the so-called *under-investment* in *R&E* activities in agriculture: Griliches (1958) for corn in U.S.A.; Ayer and Schuh (1972) for cotton in Brazil; Evenson and Kislev (1991) for sugarcane in South Africa; Hayami and Akino (1977) and Ito (1989) for rice in Japan, to name only a few. It is thus intriguing to examine whether or not the Taiwanese rice sector has experienced a similar situation of *under-investment* in the public *R&E* activities since the mid-1970s.

This study is organized as follows. Section two offers a brief survey on the public *R&E* activities in Taiwanese agriculture during the post World War Two period. Section three introduces a translog variable (or restricted) cost function framework to examine the impacts of the stock of technological knowledge defined as an accumulated *R&E* capital stock on the magnitude and bias of technological change. It also presents the method to compute the shadow price and social internal rate of return to the stock of technological knowledge. Section four discusses the data necessary for the empirical estimation of the translog cost function. Section five presents and evaluates the empirical results. Finally, in section six, the results are summarized and some concluding remarks are offered.

2 Movements in the R&E Investments in Taiwanese Agriculture

Many agricultural research institutions in Taiwan were established during the Japanese occupation before the Second World War. After the War, however, the Sino-USA Joint Commission on Rural Reconstruction (JCRR in short) were engaged in giving advises and monetary supports to the Taiwanese government. Such advises and supports were not only expanded and improved the institutions inherited from the Japanese government but also made possible for the establishment of various new research institutions such as the Taiwan Agricultural Research Institute and the Taiwan Livestock Research Institute[1].

---

[1] See Yager(1988) for details.

As a result, many new technologies were developed in the agricultural research institutions and agricultural experiment stations, and were improved and diffused by the *Nokai* (agricultural council). The research and extension activities by the public research institutions and experimental stations must have played an important role in raising agricultural (total as well as single factor) productivity. In particular, for the improvement of rice seed varieties, the Taiwanese rice sector has not only successfully accumulated the results of the research and development before the Second World War, but also promoted the improvement of new seed varieties and new production technologies such as mechanization.

In general, most of the research activities in the Taiwanese agriculture are executed by the public research institutions. To confirm this, let us look into the movements of the expenditures on research and extension for the agricultural sector. Figure 1 shows the movements of the research and extension expenditures over the 1954-86 period. The data were collected by Shih, Fu, and Chen (1990) for the agricultural sector for the 1954-86 period (unfortunately, not for the rice sector specifically). They were deflated by the GNP deflater and then expressed in million NT dollars at 1986 prices.

As evident from the figure, both research and extension expenditures in real terms increased sharply since 1970. In particular, the rate of increase in extension expenditures was so large that the expenditures on extension activities surpassed those of research activities in the 1980s. The following observation may be noteworthy at this point. Judd, Boyce, and Evenson (1991) have pointed out that it is fairly common in developing countries that expenditures on extension activities exceed those on research activities in the early stages of diffusions of agricultural technologies. However, the reverse was true in Taiwan. That is, the research expenditures exceeded the extension expenditures from the early stages (the 1950s and 1960s) of agricultural growth up to the late stage (the early-1980s), and this tendency was reversed in the mid-1980s[2]. This implies that the Taiwanese government attached greater importance to research activities than to extension activities during the 1950s through the early-1980s.

---

[2] In Japanese agriculture also, the extension expenditures were almost equal to or greater than the research expenditures during the 1950s (Ito 1994). For the rice sector specifically, the former exceeded the latter consistently for the 1950s through the early-1960s (Ito 1989).

Next, let us investigate the parity which is often used as a measure of efficiency of investment in a research activity. It is calculated as the ratio of the research expenditures to the total agricultural product. This parity criterion indicates that the lower the parity, the higher the rate of returns to the investment[3]. The parity of the Taiwanese agriculture as shown in Figure 2 was as low as around 0.6 to 0.5 percent during the early-1970s. However, it increased sharply from around 0.5 in 1974 to almost 1.2 percent in 1981. Though it decreased to around 1.0 percent in the early-1980s, it started to increase again since 1984 and reached almost 1.2 percent in 1986. These parity values are larger than those obtained by Anderson and Hayami (1986); around 0.2 to 0.3 percent for the 1959-74 period and around 0.5 percent even for the 1977-80 period. Contradictory to their finding, the values of this study are comparable to those of middle-income countries obtained by Anderson and Hayami.

Finally, based on the *R&E* expenditures, the stock of technological knowledge for the agricultural sector was estimated for the 1976-93 period using the benchmark year method[4]. It is expressed in million NT dollars at 1986 prices and presented in Figure 3. From the figure, it can be seen that the stock of technological knowledge has increased with a slight acceleration from around 5 billion NT dollars in 1976 to almost 40 billion NT dollars in 1993; almost a 8-time increase in 17-year period. In the following sections, the effects of the stock of technological knowledge on various aspects of the Taiwanese rice production will be quantitatively estimated.

3 Methodology

This study uses a variable cost function framework to measure the technology structure and the impacts of the stock of technological knowledge defined as an accumulated capital stock of *R&E* expenditures[5] on the extent and direction of the bias of technological change in the Taiwanese rice sector. The most important reason for utilizing the cost function instead of the production function approach is that it is much easier to obtain the characteristics of the production technology such as the scale elasticity and elasticities of

---

[3] See Ruttan (1982) for details.

[4] A detailed explanation is given in section four.

[5] The terms, the stock of technological knowledge, the capital stock of *R&E*, and the *R&E* capital stock are used interchangeably in this study.

factor demand and substitution (Christensen and Greene 1976).

It is assumed that the farm-firm has a production function which satisfies the neoclassical regularity conditions:

$$Q = F(X, Z, TK) \tag{1}$$

where Q is the quantity of output, X is a vector of the variable factor inputs, Z is a vector of the fixed factor inputs, and TK is a flow of technological knowledge. Because TK implies research output, it is assumed to be produced through a research production function:

$$TK = \psi(R) \tag{2}$$

where R is a stock of technological knowledge which is associated with the present and previous research. It is also implicitly assumed that an increase in R will increase TK, i.e., $dTK/dR > 0$ (Anderson 1991). Using equation (2), the production function (1) can now be rewritten as:

$$Q = F(X, Z, \psi(R)) \tag{3}$$

It is further assumed that the farm-firm employs a certain combination of factor inputs so as to minimize the variable (restricted) cost given a certain level of output and the prices of variable factor inputs, the quantities of fixed inputs, and that the state of technology which is represented by the research production function (2). Hence, there exists a cost function which is a dual of the production function (Diewert 1974):

$$C = H(Q, P, Z_B, \psi(R)) \tag{4}$$

where P is a price vector of the variable factor inputs which corresponds to a vector of the variable factor inputs (X) composed of labor (X_L), intermediate inputs (X_I), and capital (X_K), Z_B is the quantity of land as a fixed input, and $C = \sum_{i=1}^{3} P_i X_i$ is the minimized variable cost.

It may be relevant here to point out three important qualifications on the use of the variable R. First, the accumulated capital *stock* of public *R&E* expenditures is explicitly defined for R, because it is considered that the capital stock of *R&E* expenditures instead of the annual *flow* of them produce technological knowledge through the research production function (Anderson

1991). Second, R is a simple sum of the capital stock of expenditures on public research activities and the capital stock of expenditures on public extension activities. Due to its ambiguity, the impacts of the capital stock of extension expenditures on agricultural productivity are not differentiated from those of the capital stock of research expenditures. If a distinction between them is to be made, a separate extension variable should be used in the production and/or cost functions. Even if the extension's role is to be viewed as improving the quality of labor and other inputs, its effect on productivity can be considered similar to that of research. Due to these reasons, the two series of capital stock of research and extension expenditures are combined. A third qualification is that since the *R&E* expenditures in this study do not include the private sector research expenditures, the estimated effects of the capital stock of *R&E* expenditures on productivity and factor biases would have the tendency to be overestimated. Finally, as exposed in section four, the stock of technological knowledge R is for the whole agricultural sector instead of the rice sector specifically due to lack of data. Because of this nature, the estimated results may be somewhat biased.

In order to obtain the quantitative impacts of the stock of technological knowledge on the extent and the bias of technological change, the following translog form is specified for the cost function (4).

$$\begin{aligned}
\ln C \;=\;& \alpha_0 + \alpha_Q \ln Q + \sum_{i=1}^{3} \alpha_i \ln P_i + \beta_B \ln Z_B + \beta_R \ln R \\
& + \frac{1}{2}\gamma_{QQ}(\ln Q)^2 + \frac{1}{2}\sum_{i=1}^{3}\sum_{j=1}^{3} \gamma_{ij} \ln P_i \ln P_j \\
& + \sum_{i=1}^{3} \theta_{iB} \ln P_i \ln Z_B + \frac{1}{2}\theta_{BB}\,(\ln Z_B)^2 \\
& + \sum_{i=1}^{3} \delta_{Qi} \ln Q \ln P_i + \delta_{QB} \ln Q \ln Z_B \\
& + \mu_{QR} \ln Q \ln R + \sum_{i=1}^{3} \mu_{iR} \ln P_i \ln R \\
& + \beta_{BR} \ln Z_B \ln R + \frac{1}{2}\beta_{RR}(\ln R)^2, \qquad (5)
\end{aligned}$$

where $\gamma_{ij} = \gamma_{ji}$ and $i = j = L, I, K$.

The cost share (S_i) and revenue share (S_Q) equations are derived through Shephard's (1970) lemma as

$$\begin{aligned} S_i &= \frac{\partial C}{\partial P_i}\frac{P_i}{C} = \frac{\partial \ln C}{\partial \ln P_i} \\ &= \alpha_i + \sum_{i=1}^{3} \gamma_{ij} \ln P_i + \delta_{Qi} \ln Q + \theta_{iB} \ln Z_B + \mu_{iR} \ln R \qquad (6) \end{aligned}$$

$$\begin{aligned} S_Q &= \frac{\partial C}{\partial Q}\frac{Q}{C} = \frac{\partial \ln C}{\partial \ln Q} \\ &= \alpha_Q + \sum_{i=1}^{3} \delta_{Qi} \ln P_i + \gamma_{QQ} \ln Q + \delta_{QB} \ln Z_B + \mu_{QR} \ln R \qquad (7) \end{aligned}$$

$$i = j = L, I, K.$$

Any sensible cost function must be homogeneous of degree one in input prices. In the translog cost function (5) this requires that $\sum_{i=1}^{3} \alpha_i = 1$, $\sum_{i=1}^{3} \gamma_{ij} = 0$, $\sum_{i=1}^{3} \delta_{Qi} = 0$, $\sum_{i=1}^{3} \theta_{iB} = 0$, and $\sum_{i=1}^{3} \mu_{iR} = 0$ $(i = j = L, I, K)$. The translog cost function (5) has a general form in the sense that the restrictions of homotheticity and neutrality of technological change with respect to the stock of technological knowledge R are not imposed a priori. Instead, these restrictions will be statistically tested in the process of estimating the function.

First, if the primal production function is homothetic, then the dual cost function can be written as $C = I(Q, R) \cdot J(P, Z_B, R)$. This implies that the following set of restrictions on the translog cost function (4): $\delta_{Qi} = 0$ $(i = L, I, K)$, implying that changes in output level do not have any effect on the cost shares.

Next, constant returns to scale can also be easily tested in the cost function framework. If the primal production function exhibits constant returns to scale, then the cost function can be written as $C(Q, P, Z_B, R) = Q \cdot J(P, Z_B, R)$. This implies the following set of parameter restrictions on the translog cost function (5): $\alpha_Q + \beta_B = 1$, $\delta_{Qi} + \theta_{iB} = \delta_{QB} + \theta_{BB} = \gamma_{QQ} + \delta_{QB} = \mu_{QR} + \beta_{BR} = 0$ $(i = L, I, K)$.

Furthermore, the test of neutrality of technological change with respect to the *R&E* capital stock implies that the cost shares are not influenced by the changes in the *R&E* capital stock. This implies $\mu_{iR} = 0$ $(i = L, I, K)$ in the translog cost function (5).

3.1 Elasticities of Factor Demand and Substitution, and Economies of Scale

To begin with, the Allen partial elasticity of substitution (AES) can be estimated as (Binswanger 1974a):

$$\begin{aligned}
\sigma_{ij} &= \frac{\gamma_{ij} + S_i S_j}{S_i S_j} & i,j = L, I, K. \qquad i \neq j \qquad (8)\\
\sigma_{ii} &= \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} & i = L, I, K. \qquad (9)
\end{aligned}$$

Next, the own and cross price elasticities are obtained by:

$$\begin{aligned}
\epsilon_{ii} &= S_i \sigma_{ii} & i = L, I, K. \qquad (10)\\
\epsilon_{ij} &= S_j \sigma_{ij} & i,j = L, I, K. \qquad i \neq j \qquad (11)
\end{aligned}$$

Furthermore, following Caves, Christensen, and Swanson (1981), scale economies (SCE) for the case of the variable cost function of this study can be estimated as follows:

$$SCE = \frac{1 - \partial \ln C / \partial \ln Z_B}{\partial \ln C / \ln Q} = \frac{1 - \varepsilon_{CB}}{\varepsilon_{CQ}} \qquad (12)$$

where the cost-output elasticity (ε_{CQ}) is given by,

$$\varepsilon_{CQ} = \frac{\partial \ln C}{\partial \ln Q} = \alpha_Q + \sum_{i=1}^{3} \delta_{Qi} \ln P_i + \gamma_{QQ} \ln Q + \delta_{QB} \ln Z_B + \mu_{QR} \ln R \qquad (13)$$

$$i = L, I, K.$$

and the cost-land elasticity (ε_{CB}) is given by,

$$\varepsilon_{CB} = \frac{\partial \ln C}{\partial \ln Z_B} = \beta_B + \sum_{i=1}^{3} \theta_{iB} \ln P_i + \delta_{QB} \ln Q + \theta_{BB} \ln Z_B + \beta_{BR} \ln R \qquad (14)$$

$$i = L, I, K.$$

3.2 Impacts of the Stock of Technological Knowledge

First, the impacts of the stock of technological knowledge on the extent of technological change can be measured by estimating the cost elasticity with respect to the $R\&E$ capital stock (cost-$R\&E$ elasticity, hereafter). The negative of the cost-$R\&E$ elasticity ($-\varepsilon_{CR}$) indicates the effect of cost reduction due to changes in the $R\&E$ capital stock.

$$\begin{aligned} -\varepsilon_{CR} = -\frac{\partial \ln C}{\partial \ln R} &= -(\beta_R + \sum_{i=1}^{3} \mu_{iR} \ln P_i + \mu_{QR} \ln Q \\ &+ \beta_{BR} \ln Z_B + \beta_{RR} \ln R) \qquad (15) \\ & i = L, I, K. \end{aligned}$$

Next, the bias effects of the stock of technological knowledge, if any, can be captured by the non-neutral changes in factor shares due to changes in the $R\&E$ capital stock. This study modifies the bias measure proposed by Antle and Capalbo (1988). They proposed a Hicksian (1963) measure of technological change in input space in both single-product and multi-product cases by extending Binswanger's (1974b) definition of the bias measure to nonhomothetic (in the single-product case) and input-output nonseparable (in the multiproduct case) production technologies. According to their definition, the change in optimal cost shares due to technological change can be decomposed into a scale effect (a movement along the nonlinear expansion path) and a pure bias effect (interpreted as a shift in the expansion path). In the single-product case of this study where the technology index is represented by the $R\&E$ capital stock, the Hicksian bias measure may be defined in a modified way as

$$\begin{aligned} B_i^e &= \partial S_i(Q, P, Z_B, R)/\partial \ln R|_{dC=0} \\ &= B_i + (\frac{\partial \ln S_i}{\partial \ln Q})(\frac{\partial \ln C}{\partial \ln Q})^{-1}(-\frac{\partial \ln C}{\partial \ln R}) \qquad (16) \end{aligned}$$

where $B_i \equiv \partial \ln S_i(Q, P, Z_B, R)/\partial \ln R$ ($i = L, I, K.$). If $B_i^e > 0$ (< 0), then technological change caused by the stock of technological knowledge is said to be biased toward using (saving) the i-th factor. If $B_i^e = 0$, then technological change is said to be i-th factor neutral. Based on the estimated results of the B_i^e, one can examine whether or not the direction of the measured factor biases is consistent with the Hicksian induced innovation hypothesis in a modified fashion.

Using the parameters of the translog variable cost function (5), equation (9) can be expressed as

$$B_i^e = \frac{\mu_{iR}}{S_i} + \frac{\delta_{Qi}}{S_i}(-\frac{\varepsilon_{CR}}{\varepsilon_{CQ}}) \qquad (17)$$
$$i = L, I, K.$$

where (ε_{CQ}) is the cost-output elasticity given by equation (13).

Since homotheticity implies $\partial \ln S_i / \partial \ln R = 0$, i.e., $\delta_{Qi} = 0$ for all $i (= L, I, K)$, the scale effect vanishes. Thus, the Hicksian bias measure contains only the effect of a shift in the expansion path (i.e., a pure bias effect).

Furthermore, another (but, conventional) method of evaluating the effect of the stock of technological knowledge on rice production is to investigate the efficiency of investment in $R\&E$ activities by estimating the marginal productivity (MP) (or marginal rate of return to) of the stock of technological knowledge.

The MP of the stock of technological knowledge can be obtained, in the translog cost function framework of this study, by[6]

$$MP = \frac{\partial Q}{\partial R} = (-\frac{\partial C}{\partial R})/\frac{\partial C}{\partial Q} = (-\frac{\partial \ln C}{\partial \ln R}/\frac{\partial \ln C}{\partial \ln Q})\frac{Q}{R} = (-\frac{\varepsilon_{CR}}{\varepsilon_{CQ}})\frac{Q}{R} \qquad (18)$$

Equation (18) indicates that the MP of the stock of technological knowledge can be obtained by multiplying the negative of the cost-$R\&E$ elasticity ($-\varepsilon_{CR}$) normalized by the cost-output elasticity (ε_{CQ}) by the average productivity of the stock of technological knowledge (Q/R). Note here that MP as well as all the other indicators which are obtained based on the estimates of the translog cost function (5) are for individual farm-firms.

Based on the estimate of MP, the internal rate of return (IRR) to the stock of technological knowledge can be estimated. Since the stock of technological knowledge for the agricultural sector is going to be used for the estimation of the translog cost function (5), it is more relevant to estimate the *social* IRR instead of the *private* IRR. The social IRR (r) for the discrete time period can be obtained by

---

[6] Ito (1992) presents a compact mathematical derivation of the marginal productivity of the stock of technological knowledge in the cost function framework (pp.245-246).

$$(1+r)^{\theta} = \sum_{t=0}^{T} \frac{nMP_t}{(1+r)^t} \tag{19}$$

where n is the number of rice-producing farm-firms, θ is the lag of diffusion of developed technology, and T is the period of returns to investments in $R\&E$ activities.

4 The Data

4.1 Variables Other Than *R&E*

The variables required to estimate the variable cost function model are the variable cost, the total revenue and the quantity and price of total output, and the prices and cost shares of the three variable factors of production (labor, intermediate inputs, and capital), the quantity of land as a fixed input, and the stock of technological knowledge. A pooled cross-section of time-series data were collected and processed for the Taiwanese rice sector for the period 1976-93 based mainly on the *Survey Report of Rice Production Costs (SRRPC)* published annually by the Food Bureau, Taiwan Provincial Government, ROC. The necessary data were collected for average farm-firm in each of the five size classes from six districts. The five size classes are less than 0.5, 0.5-0.75, 0.75-1.0, 1.0-1.5, and 1.5 hectares and over. The six districts are Taipei, Shinchu, Taichung, Tainan, Kaoshiung, and Tontai. Thus, the sample size is $18(years) \times 5(classes) \times 6(districts) = 540$. One can compile each pooled data set separately for the first and second crops. This study utilized the data set for the first crop[7]. Since the data are expressed in per-hectare terms, it is necessary to multiply the needed variables by the planted area of the average farm-firm in each size class in each district in order to express them in per-farm-firm terms.

The quantity of total output (Q) was obtained by multiplying the amount of production (kilograms) per hectare by the planted area. The price of output (P) was obtained as a simple average of the government purchasing prices (NT dollars per kilogram) for the first and second crops. The total revenue ($TR = PQ$) was estimated as a product of the total output and the price. The price data were taken from the *Taiwan Food Statistics Book*

---

[7] Indeed, the same estimations were made using the data set for the second crop. The results were very much similar in all parameters and indicators for the two crops. Thus, it may be safe to stick to the analysis based on the data set only for the first crop.

(TFSB) published annually by the Food Bureau, Taiwan Provincial Government, ROC.

The cost of labor input ($C_L = P_L X_L$) was defined as the sum of the wage bills for family and hired labor and the wage bill for contract work. This was multiplied by the planted area to yield the farm-firm level labor cost. As for the price of labor (P_L), the Törnqvist-Theil index was obtained by the Caves-Christensen-and-Diewert (CCD) (1982) method. The CCD method is most relevant when it comes to estimating the Törnqvist-Theil index for a pooled cross-section of time-series data set. All other indexes were obtained based on this method. The *SRRPC* reports the wage bills for family labor, hired labor, and contract labor and the hours worked and the average wage rate for each category separately for male and female. In each category, a weighted average wage rate of male and female labor is estimated in the *SRRPC* by dividing the sum of the wage bills for male and female labor by the sum of the male and female labor hours worked. For these wage bills and weighted average wage rates, the CCD method was applied.

Unfortunately, however, the wage bills and weighted average wage rates are reported only for the average farm-firm in each district. Therefore, the same price of labor has to be used for the five different size classes in each district.

The cost of capital ($C_K = P_K X_K$) was defined as the sum of the wage bills for animal service and machinery service and expenditures on farm buildings, equipment, and tools. The sum of these expenditures was multiplied by the planted area in order to obtain the cost of capital input for the farm-firm. The price index (P_K) of capital input was obtained by the CCD method in a very similar fashion as in the case of labor input. In this estimation, the price index for farm machinery was used for the complex of farm buildings, equipment, and tools taken from the *TFSB*. In this case also, the wage bills and the wage rates for animal and machinery services are reported only for the average farm-firm in each district. However, the expenditures on farm buildings, equipment, and tools are reported for the average farm-firms of the five size classes in all districts. It was found from the computation that these expenditures' shares in the total capital costs are very small. Thus, it is safe to say that there would not be much differences in P_K among different size classes in each district.

The cost of intermediate inputs ($C_I = P_I X_I$) was defined as the sum of expenditures on seeds, materials, agri-chemicals, and fertilizers. This sum was multiplied by the planted area, yielding the cost of intermediate inputs of the farm-firm. The price index (P_I) was obtained by the CCD method. In this estimation, the price indexes for these items were obtained from the *TFSB.*

As for land (Z_B), because it is treated as a fixed input, the planted area was used. The price of land (P_B) was defined as land rent per hectare. These variables are reported for each size class in each district in the *SRRPC.*

The variable cost (C) can now be estimated as $C = P_L X_L + P_I X_I + P_K X_K$. The cost share of each variable factor input and the revenue share can be obtained as $S_i = C_i/C$, i=L,I,K, and $S_Q = TR/C$.

4.2 Estimation of the Stock of Technological Knowledge

For the estimation of the stock of technological knowledge, the present study heavily relies on Ito (1989, pp.12-13). The necessary data for the expenditures on agricultural research and extension activities were taken from Shih, Fu, and Chen (1990). Unfortunately, their data are for the whole agricultural sector, not for the rice sector specifically. Accordingly, the compiled stock of technological knowledge will be over-estimated. However, one could not tell *a priori* in which way the computed impacts on the production structure will be biased, i.e., over- or under-estimation, because the parameters (in particular, those related to the variable $\ln R$) of the translog variable cost function (5) will be biased due to the overestimation of the stock of technological knowledge. Thus, the evaluations of the estimated results will entail qualifications[8]. The *R&E* expenditure data were deflated by the GNP deflater in order to construct the stock of technological knowledge[9].

Now, the stock of technological knowledge is determined by the annual

---

[8] One may estimate the stock of technological knowledge for the rice sector specifically by, say, using the ratio of rice product to total agricultural product as a weight. However, this may be too arbitrary to apply to the present study. Instead, it may be more realistic to consider in such a manner that, though very little, there may be certain amount of spillovers from the *R&E* activities in other crop (and even livestock) production. Thus, the basic data for the whole agricultural sector collected by Shih, Fu, and Chen were used as they are.

[9] The appropriate deflater such as the deflater for research and extension expenditures in agriculture are not available at present.

investments on research activities and the appropriate weights. The weights are determined by the lag structure and the speed (or rate) of obsolescence of the stock of technological knowledge. Ito (1989) obtained approximately five years for the average years of research lag period in the Japanese rice sector for the 1960-90 period. As for the rate of obsolescence of the stock of technological knowledge, following Goto et al. (1986), he assumed 10 percent per year. Due to lack of data information on the obsolescence rate for the Taiwanese rice sector, this study assumes 5, 6, and 7 years for the research lag period and 10 percent of the obsolescence rate based on the estimates for the Japanese rice sector by Ito.

The stock of technological knowledge was estimated by the benchmark year method as follows. If it is assumed that R_t is the stock of technological knowledge at the end of year t, then the following equation can be obtained.

$$R_t = G_{t-5} + (1 - \delta_R)R_{t-1} \tag{20}$$

where δ_R is the rate of obsolescence of the stock of technological knowledge and G_t is the research expenditure (investment) in year t which is added to the stock of technological knowledge with, say, a 5-year lag. Assuming that the annual rate of change in this stock is g, equation (20) can be written as

$$R_t = G_{t-5} + (1 - \delta_R)R_{t-1} = (1 + g)R_{t-1}. \tag{21}$$

Thus, the stock at the bench mark year (in this study 1977) R_s can be expressed as

$$R_s = G_{s-4}/(\delta_R + g) \tag{22}$$

Note that one cannot obtain the value of g before obtaining the stock of technological knowledge. It was assumed here that during the period when the stock of technological knowledge is still small, the growth rate of the stock of technological knowledge is equal to that of the flow of the expenditures on research activities. It was 14 percent for the 1974-77 period.

Using (20) through (22), the stock of technological knowledge for the 1976-93 period was estimated. Furthermore, a sensitivity analysis was also conducted where two more series of stocks of technological knowledge for the 1976-93 period for 6- and 7-year lags were obtained. In these cases, however, the same rates, 10 percent each, were also assumed for δ_R and g.

Next, Ito did not introduce any lag structure for the extension activities. That is, he added the flow amount of expenditures on extension activities to the stock of technological knowledge each year.

Since it is generally known that it takes several years for a new technology to be adopted and materialized in rice production, the present study assumes five years as a maximum for extension activities for a particular innovation.[10] In addition, for a sensitivity analysis purpose, it also assumes three years. Using a similar procedure as used for the stock of technological knowledge, i.e., the benchmark year method, two series of capital stocks of extension activities were estimated for 3- and 5-year lags. In this case, 17 percent was obtained for the rate of growth of the capital stocks based on the growth rate of extension expenditures (investment) for the 1974-77 period. However, since there is no reliable information for the rate of obsolescence of the capital stock of extension activities, as in the case of the stock of technological knowledge, a 10 percent rate was adopted.

As Ito did, this study assumes that the stocks of technological knowledge and extension activities together yield the stock of technological knowledge which is materialized on actual farms. Thus, the two capital stocks were added together for each year for the 1976-93 period. It is expressed in million NT dollars at the 1986 prices.

Although this study uses farm-firm level data, the estimated stock of technological knowledge for the whole agricultural sector is used because of its non-excludability nature as a public good. It is thus assumed that each rice producing farm-firm in each size class in the six districts enjoys the same amount of the stock of technological knowledge in each year.

Finally, since there are three series of stocks for technological knowledge and two series of stocks for extension expenditures, respectively, there are altogether six different combinations. These six combinations of the stocks of technological knowledge were used for the sensitivity analysis based on the estimating equation system composed of equations (5), (6), and (7). The estimated results for the six options of the stocks of technological knowledge were in general very similar. However, the combination of 7-year lag for research and 3-year lag for extension investments gave the best results in terms of the R^2s and the t-statistics of the coefficients as well as monotonicity

---

[10] This assumption is based on personal discussions with extension people.

and concavity conditions. Thus, this option was used for the variable R in the present study.

5 Statistical Method

For statistical estimation, since the quantity of output(Q) in the right-hand-side of the cost function (5) is in general endogenously determined, a simultaneous estimation procedure should be employed in the estimation of the set of equations consisting of the cost function (5), two of the three cost share equations (6), and one revenue share equation (7). The method chosen was iterative three stage least squares (I3SLS). The I3SLS procedure is an extension to simultaneous-equation system of the Zellner (1962) treatment of groups of seemingly unrelated regression equations which contain jointly dependent endogenous variables (Johnston 1972, pp. 395-400). The required instrumental variables consisted of the variables which are exogenous to the cost structure, i.e., the prices of output and inputs including land, land area, and $R\&E$ stock. In this process, the restrictions due to symmetry and linear homogeneity in prices were imposed. The coefficients of the omitted (i.e., the capital) cost share equation were obtained using the linear homogeneity restrictions after the system was estimated.

6 Empirical Results

6.1 Hypothesis Testings and Final Specification of the Cost Function

For the tests of the three hypotheses, i.e., homotheticity, constant returns to scale, and Hicks neutrality, a Wald Chi-square test was applied. The computed Chi-square statistics for these three hypotheses were 674.7, 5.2, and 730.1 with the degrees of freedom, 3, 7, and 4, respectively. The critical values at the 0.05 significance level for these degrees of freedom are 7.8, 14.1, and 9.5. Thus, the hypotheses of homotheticity and Hicks neutrality were strongly rejected at the 0.05 significance level. However, the hypothesis of constant returns to scale could not be rejected at the 0.05 significance level. This implies that there exist constant returns to scale in the Taiwanese rice sector. This indicates that when the farm-firm increases the scale of rice production in terms of output, the average production cost per unit of output will increase proportionately[11].

Thus, the system of equations (5), (6), and (7) were reestimated with an additional imposition of the parameter restrictions of constant returns to scale [12]. The coefficients of the omitted (in the present case, the capital) cost share equation were obtained using the parameter relations of linear homogeneity restrictions. The results are presented in Table 1. The computed R^2's were 0.923, 0.766, 0.641, and 0.666 for the variable cost function, labor share equation, intermediate-inputs share equation, and revenue share equation. Furthermore, the (asymptotically) computed t-statistics are fairly large, indicating that the estimated coefficients are statistically significant except for two coefficients (γ_{IK} and θ_{KB}). Thus, it can be said that the goodness of fit is considerably good. In addition, monotonicity and concavity were also checked and satisfied not only at the approximation point but also at all the sample observations. This set of estimates is thus referred to as the final specification of the model and will be used for further analyses.

6.2 Factor Demand and Substitution Elasticities

Factor demand elasticities with respect to factor prices, output quantity, and land area as well as the Allen partial elasticities of substitution were computed at the approximation point and are reported in Tables 2 and 3, respectively. Several important findings emerge from the tables.

First, the own-price elasticities of demand for all the variable factors, i.e., labor, intermediate inputs, and capital, are less than unity in absolute values (0.277, 0.384, and 0.525, respectively), indicating inelastic demand for these factor inputs by farm-firms. However, the demand elasticity for capital is the largest in absolute values among the three elasticities. Considering the fact that the most important element of capital input is machinery service, rice producers are relatively more sensitive to changes in the price of machinery service than to the changes in the prices of labor and intermediate inputs.

Second, the demand for the three variable factor inputs with respect to output quantity are rather elastic; they are 1.4, 2.1, and 1.6 for labor,

---

[11] This result is consistent with that of Kuroda (1996) where the time variable was used as an index of technological change instead of the stock of technological knowledge as an accumulated capital stock of *R&E* investments.

[12] Furthermore, due to the parameter restrictions for constant returns to scale, i.e., $\alpha_Q + \beta_B = 1$, $\delta_{Qi} + \theta_{iB} = \delta_{QB} + \theta_{BB} = \gamma_{QQ} + \delta_{QB} = \mu_{Qt} + \beta_{Bt} = 0$ $(i = L, I, K)$, SCE estimated using equations (12), (13), and (14) was unity for all the sample observations.

intermediate inputs, and capital, respectively. The relative magnitudes of these elasticities imply that an expansion of rice production requires a higher utilization level of intermediate inputs than labor and machinery services.

Third, the demand elasticities for labor, intermediate inputs, and capital with respect to land are 0.87, 0.15, and 0.63, respectively. This implies that a one percent expansion of planted area of rice requires almost 0.9 percent increase in labor employment, but a less proportional increase in capital. However, a one percent increase in land area requires only 0.15 percent increase in intermediate inputs.

Fourth, the AESs between labor and intermediate inputs, labor and capital, and intermediate inputs and capital are 0.03, 0.73, and 1.01, respectively. This indicates that labor and intermediate inputs are almost independents, but labor and capital, and intermediate inputs and capital are fairly good substitutes[13].

6.3 Cost Reducing Effects of the Stock of Technological Knowledge

The negative of the cost-*R&E* elasticity $(-\varepsilon_{CR})$ was estimated using equation (15) for each year of the 1976-93 period. To be more specific, the estimation was carried out for each of the five size classes in each of the six districts. Since there exist only slight differences in the magnitudes of the $(-\varepsilon_{CR})$s among the six districts, the Taipei district was chosen as a representative. The $(-\varepsilon_{CR}$s) for the Taipei district are shown in Figure 4. In addition, as a reference, the rates of technological change for the Taipei district were estimated based on the parameter estimates of the variable cost function where the time trend was used as an index of technological change instead of the *R&E* capital stock. They are presented in Figure 5.

At least, two important features are noteworthy in Figures 4 and 5. First, the rate of technological change given in Figure 5 can be classified into four trends: (1) it increased sharply from around 0.5 to 1.6 percent for the 1976-80 period; (2) it then slowed down from 1.6 to 2.0 percent for the 1980-1986 period; (3) it increased sharply again from 2.0 to 3.5 percent for the 1986-

---

[13] These results on the elasticities of the factor demand and substitution are very much similar in terms of the magnitudes to those obtained using the parameter estimates of the variable cost function where the time variable was used as an index of technological change (see Kuroda, 1996, Tables 2 and 3).

90 period; and (4) it became stagnant for the 1990-93 period with the rate around 3.5 to 3.7 percent. These rates of technological change may be said to be fairly high for agricultural production, indicating that the rice sector in Taiwan has shown a good performance in the development and diffusion of new technologies since the mid-1970s. In Figure 4, one can observe very similar movements in the negative of the cost-$R\&E$ elasticities for the same study period. That is, the cost reducing effects of the $R\&E$ capital stock had an increasing trend during the mid-1970s through the 1980s and became stagnant in the early-1990s. This indicates that research and extension activities by the government have played an important role in raising the productivity in the Taiwanese rice sector since the mid-1970s. Furthermore, the introduction of policies such as farmland consolidation, scale enlargement, and mechanization during this period must have been the impetus to the impressive performance in technological progress in the Taiwanese rice production.

Another feature is that not only the negative of the cost-$R\&E$ elasticities, but also the technological change rates are very similar and consistent among the five size classes for the whole period. This indicates that the technological diffusion has been neutral irrespective of size classes in Taiwanese rice production. This finding is consistent with the fact that in any villages almost all rice producing farmers utilize very similar production technology.

6.4 Biases With Respect To the Stock of Technological Knowledge

The biases of technological change with respect to the stock of technological knowledge measured in the $R\&E$ capital stock B_i^e $(i = L, I, K)$ were estimated using equation (17) for each of the five size classes in each of the six districts throughout the sample period. The biases are expressed in terms of elasticities. Again, since there exist only slight differences in the magnitudes and movements of the biases among the six districts, the Taipei district was chosen as a representative. Figures 6, 7, and 8 show the biases for labor, intermediate inputs, and capital for the 1976-93 period in the Taipei district. As in the case of the negative of the cost-$R\&E$ elasticities and the technological change rates, the movements and magnitudes of the biases over time are very much similar among the five size classes.

First, as seen in Figure 6, technological change due to *R&E* activities was biased toward saving labor. This is shown by the negative elasticities over the entire study period. The degree of the labor-saving bias increased consistently over time from around 0.30 in 1976 to around 0.62 in 1993 in absolute values. This finding corresponds to the accelerated migration of labor from the agricultural to nonagricultural sectors during this period.

Second, Figure 7 shows that the technological change due to *R&E* activities was biased toward using intermediate inputs. With the exception of 1989, the extent of the intermediate-inputs-using bias appears to have shown an increasing trend with the elasticities being around 0.4 to 0.6. This finding is consistent with the rapid increase in the utilization of chemical-fertilizers and agri-chemicals for rice production in Taiwan.

Third, Figure 8 shows that the technological change due to *R&E* activities was biased toward using capital, and the bias was as large as around 0.44 in 1976 but consistently slowed down to 0.24 in 1993. This finding is consistent with the rapid mechanization in the Taiwanese rice production during the late 1970s and the pace-down or stagnation after that.

At this point, let us compare these biases with the relative movements of the factor prices in order to test whether or not the Taiwanese rice production is consistent with the Hicks induced innovation hypothesis. As described in section three, the factor price indexes were obtained for each size class in each district by the CCD method. Setting the 1976 values of size class 1 of the Taipei district to one, the price indexes were rearranged. A quick investigation of these index numbers tells us that the basic movements of the price indexes are almost the same among different size classes within a district, but seem to be slightly different among different districts. Thus, as a representative, the price indexes of size class 1 of the Taipei district are given in Figure 9. From the figure, one can observe that the prices of intermediate inputs and capital relative to that of labor decreased over time. This indicates that labor is relatively scarce compared to intermediate inputs and capital. As found above, the biases were toward saving the relatively more expensive factor input, i.e., labor, and toward using relatively less expensive factor inputs, i.e., intermediate inputs and capital. This finding may thus be said to be consistent with the Hicksian induced innovation hypothesis. This in turn implies that the government *R&E* activities have been sensitive to the price signal of the factor markets in the Taiwanese rice production.

6.5 Shadow Price of and the Internal Rate of Return to the Stock of Technological Knowledge

The shadow price (or marginal productivity) (MP) of the stock of technological knowledge was estimated using equation (18) for each of the five size classes in each of the six districts for each year of the 1976-93 period. It is expressed in NT dollars per million Nt dollars of the stock of technological knowledge. Again, since there exist only slight differences in the magnitudes and movements of the MPs among the six districts, the Taipei district was chosen as a representative.The results are shown in Figure 10. At least, two important features are noteworthy from the figure.

First, the MPs in all the size classes increased fairly sharply from 1976 to 1980. The movements were found to be parallel among the five size classes. After 1980, however, they gradually decreased in a similar fashion. It is also interesting to note that the MP of the largest size class had an increasing trend for the 1989-93 period. Second, it was found that the larger the size class, the greater the magnitudes of the MPs. In particular, the MP of the largest size class is much greater than those of the other size classes for the entire 1976-93 period. What are the causes for such differences among size classes? To answer this question, it is convenient to go back to equation (18). It was found that there exist only slight differences in the magnitudes of the $-\varepsilon_{CR}$s among the five size classes in all the six districts. Furthermore, it was also found that there exist constant returns to scale in the Taiwanese rice sector, which implies that ε_{CQ} is unity. In addition, the stock of technological knowledge R is the same for all farms in each year. Therefore, it is clear that differences in the MPs come mainly from differences in the scale of output. This result may imply that in order to utilize the stock of technological knowledge more efficiently, a larger scale farming should be introduced in the Taiwanese rice sector.

Next, using equation (19), the *social IRR* of the stock of technological knowledge was calculated for the Taiwanese rice sector as follows. First, a simple average marginal productivity of the five size classes of the six districts used in this study was estimated for each year of the period 1976-93. Then, this average marginal productivity was multiplied by the total number of farm households. Finally, a simple average of marginal productivity multiplied by the number of farm households was obtained for the 1976-93 period. This average marginal productivity was used for nMP in equation (19) to yield the *social* IRR to the stock of technological knowledge in the Taiwanese rice sector[14]. Assuming the period of investment returns T to be infinity and the lag of diffusion θ to be five years in equation (19)[15], the estimated *social* IRR turned out to be 45 percent. This is comparable to the IRR of the Japanese rice production, i.e., 44.1 percent for the 1969-87 period as was obtained by Ito (1989). The estimated 45-percent IRR for the Taiwanese rice sector is much higher than the per annum market interest rate for one-year time deposits (around 8 to 9.5 percent for the 1982-90 period). This indicates that the level of investments in the $R\&E$ activities for rice production in Taiwan have been far below the optimum level as in the case of Japan.

7 Summary and Conclusions

Using the translog variable cost function framework, this study has investigated quantitatively the impacts of the public $R\&E$ activities on the production structure of the Taiwanese rice industry for the 1976-93 period . Several important findings may be summarized as follows.

1. The demand elasticities for labor, intermediate inputs, and capital are all less than unity in absolute values, indicating the demand for these inputs are not elastic.

2. The substitution elasticities between labor and intermediate inputs, labor and capital, and intermediate inputs and capital are all positive. This indicates that the three variable factor inputs are all mutually substitutable.

---

[14] This average nMP is naturally over-estimated by the following two reasons. First, the shares of larger-sized farm-firms are much smaller than those of smaller-sized farm-firms. A weighted average nMP could not be calculated simply because the data on the numbers of rice-producing farms in the five size classes are not available at present. Second, the total numbers of farm households instead of rice-producing farm households had to be used because of the data availability at hand. Accordingly, the estimated IRR will naturally be over-estimated.

[15] Following Fujita (1987) and Ito (1992) who estimated the IRR for the case of Japanese agriculture, five years are just assumed for the case of the Taiwanese rice production, since rice production technologies in Taiwan and Japan are fairly similar.

3. It was found that there exist constant returns to scale in the rice production in Taiwan. This implies that doubling the output scale will double the total cost, i.e., the average cost will remain at the same level. In other words, the small and large scale farm-firms are equally efficient in terms of average cost.

   These findings (1, 2, and 3) are very much consistent with those when the time trend was used as an index of technological change in the variable translog cost function (Kuroda 1996).

4. The cost reducing effect measured in the negative of the cost-*R&E* elasticity showed an increasing trend during the mid-1970s through the 1980s. It then became stagnant in the early 1990s with a fairly large elasticity of around 0.45 in 1989. This movement was very similar to that of the rate of technological change estimated using the parameters of the variable translog cost function where time trend was used as an index of technological change (Kuroda 1996). This indicates that the public *R&E* activities have played an important role in raising the productivity in the Taiwanese rice sector since the mid-1970s. Furthermore, the cost reduction effects of the public *R&E* activities were almost equal among the five different size classes for the study period, indicating that the technological diffusion were neutral irrespective of size classes in the Taiwanese rice sector.

5. Technological change due to the public *R&E* activities has been biased toward saving labor, and using intermediate inputs and capital. These biases have been consistent with the changes in the relative prices of these factor inputs, i.e., saving a relatively more expensive factor input (labor) and using relatively less expensive factor inputs (intermediate inputs and capital). In this sense, the public *R&E* activities have been sensitive to the price signal of the factor markets. This finding is consistent with the Hicks induced innovation theory.

6. It was found that the larger the size class, the greater the shadow prices of the *R&E* capital stock in the Taiwanese rice sector. This implies that even though the cost reducing effects of the stock of technological knowledge are almost neutral among all size classes in the Taiwanese rice sector, in order to utilize it more efficiently, a larger scale farming

is more desirable for the Taiwanese rice sector.

7. The social *IRR* of the stock of technological knowledge was 45 percent which is much greater than the market interest rate. This indicates that the level of investments in the *R&E* activities for the rice sector in Taiwan has been far below the optimum level.

As a concluding remark, it may be worthwhile considering at least one important implication of these findings for future rice production in Taiwan.

According to Y.H. Lee (1996), further liberalization of the economy, changes in food consumption patterns, and higher levels of rice imports are all expected to reduce the amount of land required for rice production in the future. Given such a condition for the future, the rice industry in Taiwan will have to be more efficient in terms of production cost. To meet this requirement, the public *R&E* activities will have to be promoted more positively in order to raise the productivity in the rice sector. To make all these realized, the *R&E* activities will have to be sensitive to the price signal of the factor markets and the production structure of the Taiwanse rice sector should be transformed toward a larger scale farming.

As a last word, at least two caveats are worth mentioning. Both are strongly related to the data set used in this study. First, although the *Survey Report of Rice Production Costs* published annually by the Food Bureau is very informative on rice-producing farm households, the wage bills and weighted average wage rates for labor are reported only for the average farm in each district. This is also true for the case of the wage bills and the wage rates for animal and machinery services. Because of this nature of the survey, the prices of labor and capital (P_L and P_K) had to be the same for the five different size classes in each district, respectively. This may have somewhat distorted the estimated results of the cost function and hence various economic indicators. Second, the data of *R&E* expenditures are for the whole agricultural sector instead of the rice sector specifically because of lack of data at present. As mentioned earlier, no arbitrary procedure was applied in order to estimate the *R&E* expenditures specifically for the rice sector using this data set. Furthermore, the information on the lag structure and the rate of obsolescence with regard to the stock of technological knowledge is also weak due to lack of data on this aspect. Therefore, the results of this paper have to be taken as preliminary. For the follow-up study, a better data set should be developed by overcoming the above-mentioned shortcomings.

References

[1] Anderson, J.R. "Agricultural Research in a Variable and Unpredictable World," in *Agricultural Research Policy: International Quantitative Perspective*, ed. Pardy, P.G., Roseboom, J., and Anderson, J.R. (Cambridge: Cambridge University Press, 1991).

[2] Anderson, K. and Hayami, Y. *Political Economy of Agricultural Protection.* (Sydney, London, and Boston: ALLEN & UNWIN In association with The Australia-Japan Research Centre and Australian National University, 1986).

[3] Antle, J.M. and Capalbo, S.M. "An Introduction to Recent Developments in Production Theory and Productivity Measurement," in *Agricultural productivity Measurement and Explanation*, ed. Capalbo, S.M. and Antle, J.M. (Washington, D.C.: Resources for the Future, 1988).

[4] Ayer, H.W. and Schuh, G.E. "Social Rates of Return and Other Aspects of Agricultural Research: The Case of Cotton Research in São Paulo, Brazil," *American Journal of Agricultural Economics*,Vol. 54, No. 4 (November 1972).

[5] Binswanger, H.P. "A Cost Function Approach to the Measurement of Elaticities of Factor Demand and Elasticities of Substitution," *American Journal of Agricultural Economics*, Vol. 56, No. 3 (August 1974a).

[6] Binswanger, H.P. "The Measurement of Technical Change Biases with Many Factors of Production," *American Economic Review*, Vol. 64, No. 6 (December 1974b).

[7] Caves, D.W., Christensen, L.R., and Diewert, W.E. "Multilateral Comparison of Output, Input, and Productivity Using Superative Index Numbers," *The Economic Journal*, Vol. 92, No. 365 (March 1982).

[8] Caves, D.W., Christensen, L.R., and Swanson, J.A. "Productivity Growth, Scale Economies, and Capacity Utilization in U.S. Railroads, 1955-74," *American Economic Review*, Vol. 71, No. 5 (December 1981).

[9] Christensen, L.R. and Greene, W.H. "Economies of Scale in U.S. Electric Power Generation," *Journal of Political Economy*, Vol. 84, No. 4 (August 1976).

[10] Diewert, W.E. "Applications of Duality Theory," in *Frontiers of Quantitative Economics*, ed. Intriligator, M.D. and Kendrick, D.A. (Amsterdam: North Holland Publishing Co., 1974).

[11] Evenson, R.E. and Kislev, Y. *Agricultural Research and Productivity.* (New Haven and London: Yale University Press, 1975).

[12] Food Bureau, Taiwan Provincial Government, ROC. *Survey Report on Rice Production Costs*, various issues.

[13] Food Bureau, Taiwan Provincial Government, ROC. *Taiwan Food Statistics Book*, various issues.

[14] Fujita, Y. *Nogyo Shido to Gijutsu Kakushin[Agricultural Guidance and Innovations].* (Tokyo: Nosangyoson Bunka Kyokai, 1987). (In Japanese).

[15] Goto, A., Honjo, N., Suzuki, K., and Takinozawa, M. "Kenkyu Kaihatsu to Gijutsu Shinpo no Keizai Bunseki[Economic Analyses of Research & Development and Technological Progress]," *Keizai Bunseki[Economic Analysis]*, No. 103 (Keizai Kikakucho Keizai Kenkyu sho, 1986). (In Japanese).

[16] Griliches, Z. "Research Costs and Social Returns: Hybrid Corn and Related Innovations," *Journal of Political Economy Agricultural Economics*, Vol. 66, No. 5 (October 1958).

[17] Hayami, H. and Akino, M. Organization and Productivity of Agricultural Research Systems in Japan," in *Resource Allocation and Productivity in National and International Agricultural Research*, ed. Arndt, T.M., Dallrymple, and Ruttan, V.W. (Minneapolis: University of Minnesota Press, 1977).

[18] Hayami, Y. and Ruttan, V.W. *Agricultural Development: An International Perspective.* (Baltimore and London: The Johns Hopkins University Press, 1985).

[19] Hicks, J.R. *The Theory of Wages*, 2nd edition. (London: Macmillan & Co., 1963).

[20] Ito, J. "Inasaku niokeru Kenkyuu-Kaihatsu Toshi no Keizaisei [Measuring the Returns to the Investments in Research and Extension Activities in Japanese Rice Production]," *Nogyo Sogo Kenkyuu*[*Quarterly Journal of Agricultural Economy*], Vol. 43, No. 4 (October 1989). (In Japanese).

[21] Ito, J. "Nogyo Kenkyu Toshi no Keizai Bunseki [An Economic Analysis of Investments in Agricultural Research and Extension Activities in Japan]," *Keizai Kenkyu*[*The Economic Review*], Vol. 43, No. 3 (July 1992). (In Japanese).

[22] Johnston, J. *Econometric Methods*, 2nd edition. (New York: McGraw-Hill, 1972).

[23] Judd, M., Boyce, J.K., and Evenson, R.E. "Investing in Agricultural Research and Extension Program: A Quantitative Assessment," in *Research and Productivity in Asian Agriculture*, ed. Evenson, R.E. and Pray, C.E. (Ithaca and London: Cornell University Press, 1991).

[24] Kuroda, Y. "An Empirical Investigation of the Rice Production Structure in Taiwan, 1976-93," Discussion Paper No. 681, Institute of Socio-Economic Planning, University of Tsukuba, Tsukuba, Ibaraki 305, Japan, 1996.

[25] Lee, Y.H. "Rice Production and Consumption, and Rice Policy in Taiwan," *Industry of Free China*, Vol. 85, No. 4 (April 1996).

[26] Ruttan, V.W. *Agricultural Research Policy.* (Minneapolis: University of Minneapolis Press, 1982).

[27] Shephard, R.W. *Theory of Cost and Production.* (Princeton: Princeton University Press, 1970).

[28] Shih, J.T., Fu, T.T., and Chen, C.H. "Returns to the Investments in Agricultural Knowledge in Post World War II Taiwan," *Academia Economic Papers*, Vol. 18, No.2 (September 1990). (In Chinese).

[29] Yager, J.A. *Transforming Agriculture in Taiwan: The Experience of the Joint Commission on Rural Reconstruction*, (Ithaka and London: Cornell University Press, 1988).

[30] Zellner, A. "An Efficient Method for Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias," *Journal of American Statistical Association*, Vol. 57, No. 298 (June 1962).

Appendix A: Figures and Tables

Figure 1. Technological Change Rate, 1976-93: Taipei (In percent)

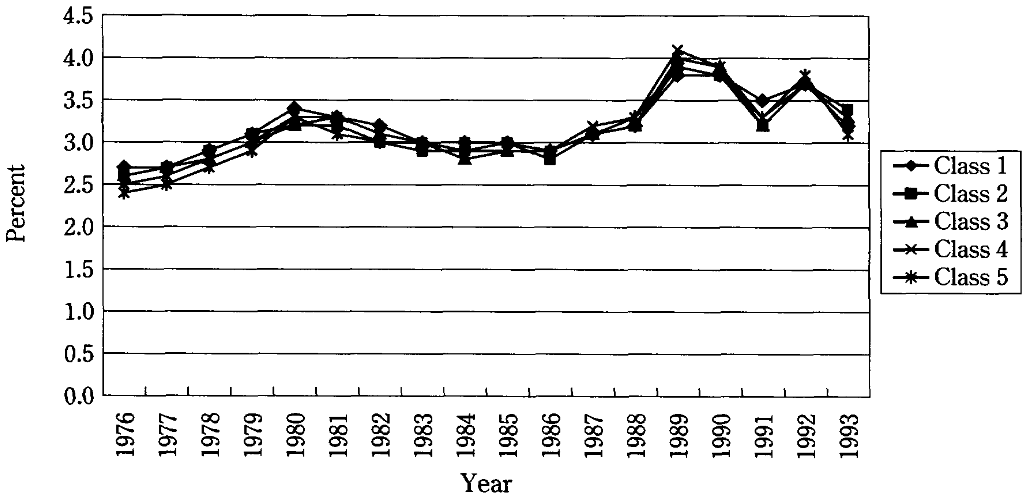

Figure 2. Public Research and Extension Expenditures for theAgricultural Sector, 1954-86 (In Million NT Dollars at 1986 Prices)

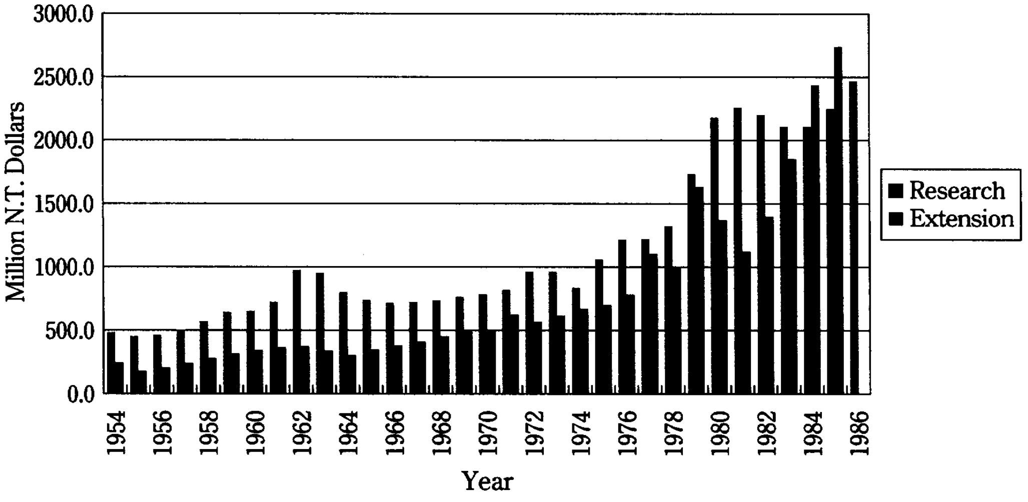

Figure 3. Ratio of R&E Expenditures to Total Agricultural Product in Taiwan, 1971-86 (In Percent)

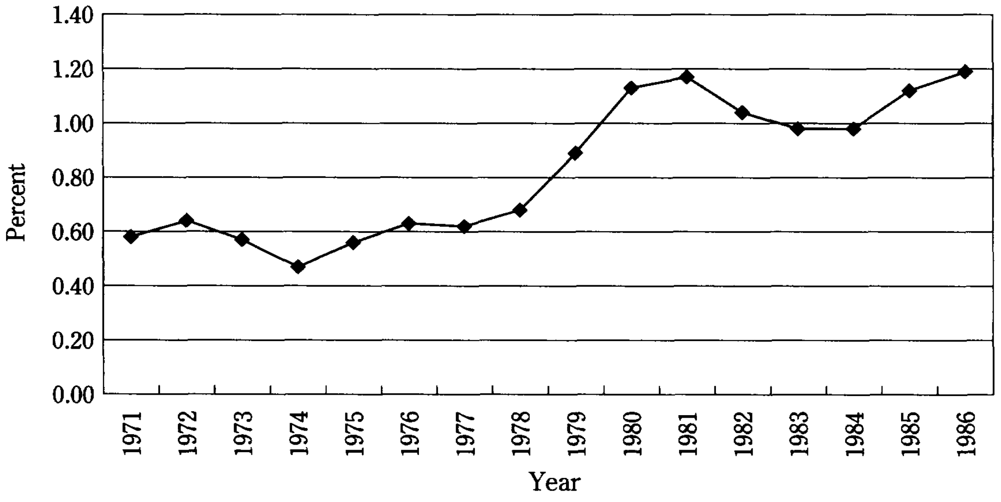

Figure 4. Stock of Technological Knowledge in the Taiwanese Agricultural Sector, 1976-93 (In Million N.T. Dollars at 1986 Prices)

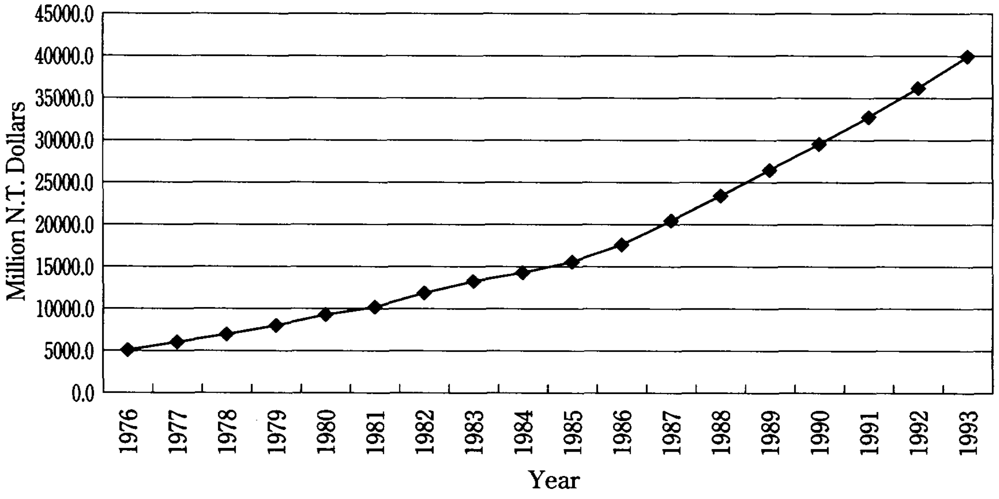

Figure 5. The Negative of the Cost-R&E Elasticity, 1976-93: Taipei

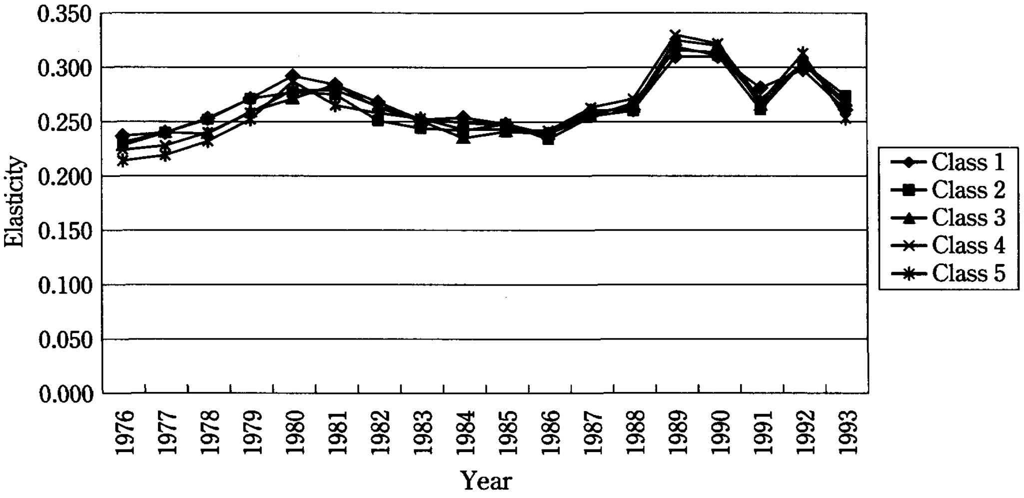

Figure 6. Labor Bias w.r.t. the Stock of Technological Knowledge, 1976-93: Taipei (In Terms of Elasticity)

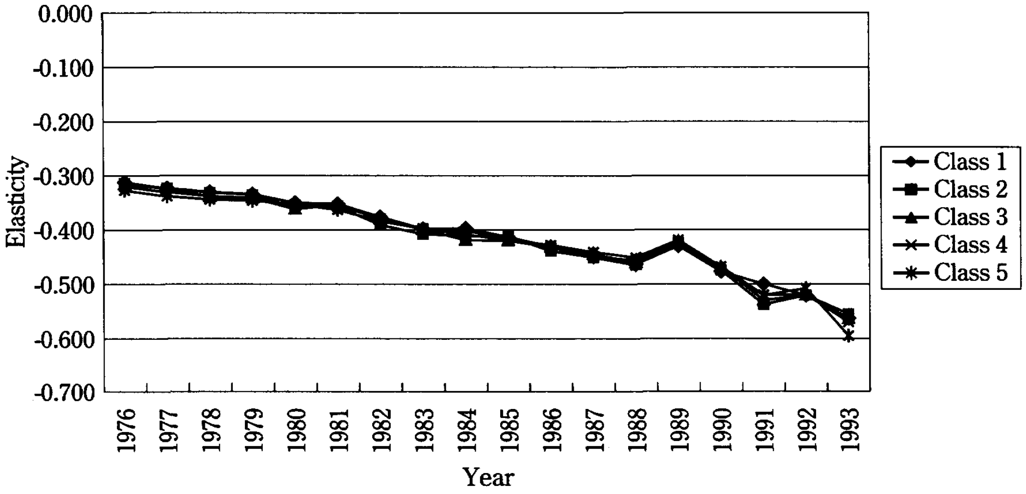

Figure 7. Intermediate-Inputs Bias w.r.t. the Stock of Technological Knowledge, 1976-93: Taipei (In Tems of Elasticity)

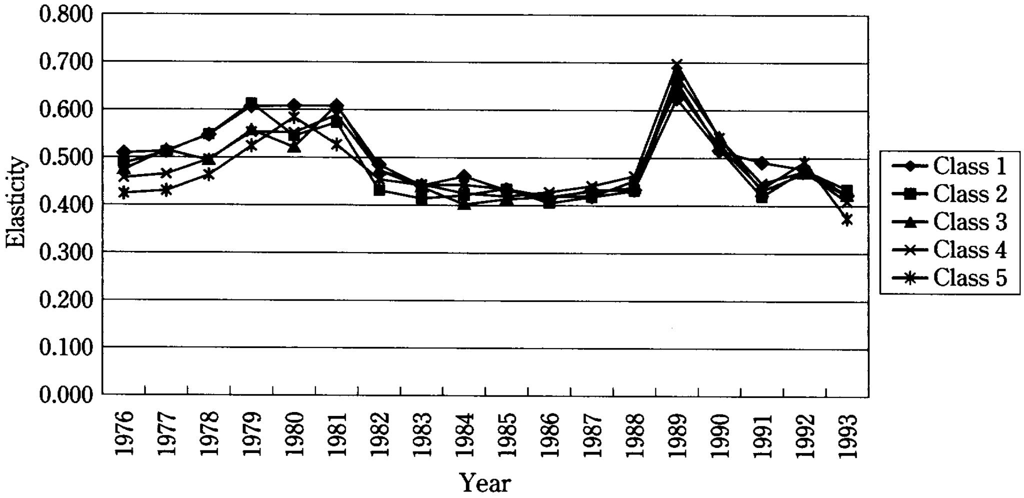

Figure 8. Capital Bias w,r,t, the Stock of Technological Knowledge, 1976-93: Taipei (In Terms of Elasticity)

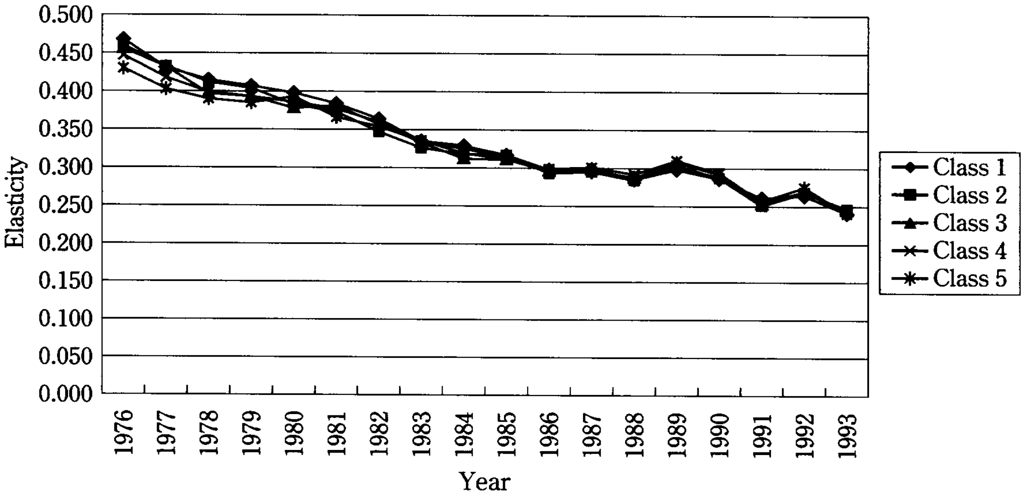

Figure 9. Factor Prices, 1976-93: Taipei, Class 1 (1976 Index Values of Class 1=1.0)

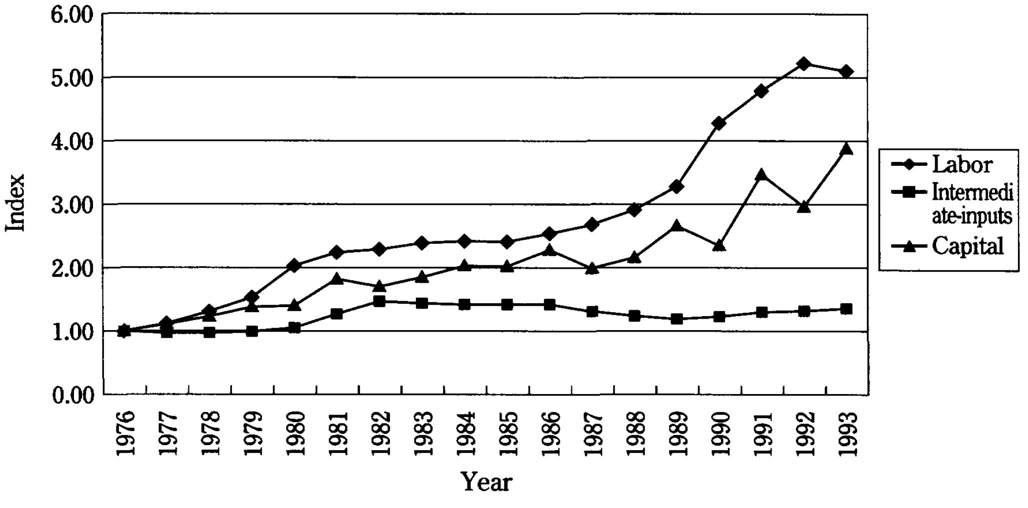

Figure 10. Shadow Price of the Stock of Technological Knowledge (STK), 1976-93: Taipei (In $N.T. per $Mil. N.T. of the STK)

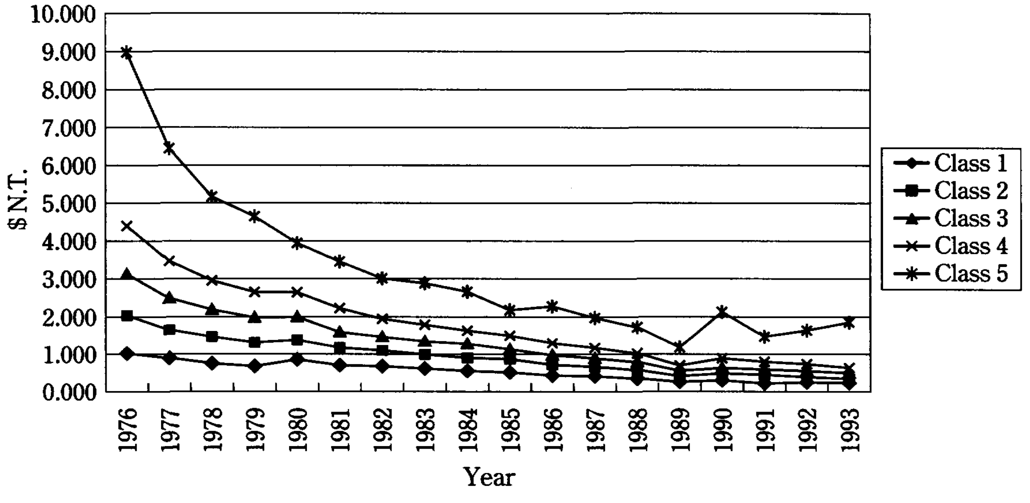

Table 1: Parameter Estimates of the Translog Cost Function for the Taiwanese Rice Sector, 1976-93

Parameter	Coefficient	t-statistic	Parameter	Coefficient	t-statistic
α_o	10.743	1034.9	θ_{LB}	0.104	6.6
α_Q	1.612	318.5	θ_{IB}	-0.105	-9.3
α_L	0.411	220.1	θ_{KB}	0.001	0.1
α_I	0.222	189.4	θ_{BB}	0.792	76.3
α_K	0.367	8.3	δ_{QL}	-0.104	-10.9
β_B	-0.622	-47.6	δ_{QI}	0.105	16.6
β_R	-0.330	-27.2	δ_{QK}	-0.001	-0.08
γ_{QQ}	0.792	19.5	δ_{QB}	-0.792	-76.3
γ_{LL}	0.128	13.5	μ_{QR}	-0.041	-7.6
γ_{II}	0.088	11.6	μ_{LR}	-0.169	-25.6
γ_{KK}	0.040	3.2	μ_{IR}	0.062	11.6
γ_{LI}	-0.088	-14.0	μ_{KR}	0.106	13.0
γ_{LK}	-0.040	-20.9	β_{BR}	0.041	3.1
γ_{IK}	0.0006	0.05	β_{RR}	-0.246	-6.4

Estimating Equations	$\bar{R}^2$
Cost function	0.923
Labor share equation	0.766
Intermediate inputs share equation	0.641
Revenue share equation	0.666

Table 2: Demand Elasticities with Respect to Factor Prices and the Quantities of Output and Land

	Labor	Intermediate Inputs	Capital
Labor Price (P_L)	-0.277	0.014	0.301
	(-60.8)	(2.6)	(21.2)
Intermediate Inputs Price (P_I)	0.008	-0.384	0.234
	(10.7)	(-7.0)	(7.0)
Capital Price (P_K)	0.269	0.369	-0.525
	(6.1)	(5.3)	(-11.4)
Output Quantity (Q)	1.369	2.093	1.618
.	(35.9)	(41.3)	(39.8)
Land Area (Z_B)	0.874	0.150	0.625
	(37.8)	(5.3)	(27.5)

Notes:
All the elasticities were estimated at the approximation point. The figures in parentheses are asymptotic t-statistics.

Table 3: Allen Partial Elasticities of Substitution

	Labor	Intermediate Inputs	Capital
Labor	-0.673	0.034	0.733
	(-60.8)	(2.6)	(21.2)
Intermediate Inputs		-1.724	1.007
		(-7.0)	(6.7)
Capital			-1.431
			(-5.2)

Notes:
All the elasticities were estimated at the approximation point. The figures in parentheses are asymptotic t-statistics.