No. 734

EFFECTS OF R&E ACTIVITIES ON RICE PRODUCTION IN TAIWAN, 1976-93

by

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June 1997

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Revised June 30, 1997

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*The author appreciates constructive and useful comments on the earlier version of this paper by Drs. Shenggen Fan and Philip G. Pardey at the International Food Policy Research Institute in Washington, D.C., Dr. Junichi Ito at the National Research Institute of Agricultural Economics in Japan, Professors D.S. Guo, T. Kako, M. Genma, and Naziruddin Abdullah, and two anonymous reviewers of this journal. He also appreciates capable computational help by Mr. Yoshihiko Yamatake. 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, the Zengin Foundation on Economics and Finance, and the Statistical Data Bank Project of the MESSC. However, the opinions expressed are those of the author alone.

1 INTRODUCTION

Taiwanese agriculture has witnessed 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 in Taiwan experienced considerably high rates of technological progress as seen in Figure 1 [1]. According to the figure, the rate of technological change can be classified into four trends: (1) it increased sharply from around 2.5 to 3.3 percent for the 1976-80 period; (2) it then slowed down from 3.3 to 2.8 percent for the 1980-1986 period; (3) it increased sharply again from 2.8 to 4.0 percent for the 1986-89 period; and (4) it appears to have started declining again for the 1989-93 period, from 4.0 percent in 1989 to 3.3 percent in 1993, although the rates were still greater than 3 percent. These rates of technological change may be said to be considerably 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. 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 (Kuroda 1997).

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.

Furthermore, 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 1997). 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 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

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[1] The estimation of the rate of technological change was carried out for each of the five size classes in each of the six districts for each year of the 1976-93 period. Since there exist only slight differences in the magnitudes of the rates of technological change among the six districts, the Taipei district was chosen as a representative (Kuroda 1997).

tantamount to investigating whether or not the public R&E activities in the Taiwanese rice sector have been sensitive to the movements 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 the Taiwanese rice sector specifically, but also information for policy makers to organize better public R&E activities for Taiwanese agriculture as a whole.

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 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 financial 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[2].

As a result, many new technologies were developed in the agricultural research institutions and agricultural experiment stations, and were improved and diffused by the

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[2] See Yager(1988) for details.

Teikoku Nokai (National 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 partial 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 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 2 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 as a whole for the 1954-86 period (unfortunately, not for the rice sector specifically). They were deflated by the GNP deflater and then expressed in million N.T. 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 [3]. This implies that the Taiwanese government attached greater importance to research activities than to extension activities during the 1950s through the early-1980s.

Next, let us investigate the parity which is often used as a measure of efficiency of investment in a research activity [4]. 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. The parity of the Taiwanese agriculture as

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[3] In Japanese agriculture also, the extension expenditures were almost equal to or greater than the research expenditures during the 1950s (Ito 1992). For the rice sector specifically, the former exceeded the latter consistently for the 1950s through the early-1960s (Ito 1989).

[4] The parity ratio is basically used to compare resource allocations to research by commodity, by factors, by production stage, by region, and among disciplines. However, it can also be used as a measure of efficiency of investment under the presumption that an additional dollar of research expenditure would have a higher return if spent on areas with relatively low ratio of research funding to output value. See Ruttan (1982) for details.

shown in Figure 3 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 [5]. It is expressed in million N.T. dollars at 1986 prices and presented in Figure 4. From the figure, it can be seen that the stock of technological knowledge has increased with a slight acceleration from around 5 billion N.T. dollars in 1976 to almost 40 billion N.T. dollars in 1993; almost an 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 [6] 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 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

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

[6] 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.

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 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 R&E 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 technological knowledge on productivity and factor biases would have the tendency to be overestimated.

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).

$$\begin{aligned}
\ln C &= \alpha_0 + \alpha_Q \ln Q + \sum_{i=1}^{3} \alpha_i \ln P_i + \beta_B \ln Z_B + \beta_R \ln R \\
&\quad + \frac{1}{2}\gamma_{QQ}(\ln Q)^2 + \frac{1}{2}\sum_{i=1}^{3}\sum_{j=1}^{3} \gamma_{ij} \ln P_i \ln P_j \\
&\quad + \sum_{i=1}^{3} \theta_{iB} \ln P_i \ln Z_B + \frac{1}{2}\theta_{BB}\,(\ln Z_B)^2 \\
&\quad + \sum_{i=1}^{3} \delta_{Qi} \ln Q \ln P_i + \delta_{QB} \ln Q \ln Z_B \\
&\quad + \mu_{QR} \ln Q \ln R + \sum_{i=1}^{3} \mu_{iR} \ln P_i \ln R \\
&\quad + \beta_{BR} \ln Z_B \ln R + \frac{1}{2}\beta_{RR}(\ln R)^2 \\
&\quad + \sum_{k=2}^{6} d_{Rk} D_{Rk} + \sum_{l=2}^{5} d_{Sl} D_{Sl}, \qquad (5)
\end{aligned}$$

where $\gamma_{ij} = \gamma_{ji}$ and $i = j = L, I, K$. Here, in order to take into account heterogeneous intercepts with respect to the six different districts and the five size classes which will be utilized in the variable compilation for the statistical estimation, regional dummies $D_{Rk}(k = 2, 3, 4, 5, 6)$ and size dummies $D_{Sl}(l = 2, 3, 4, 5)$ were introduced [7].

The cost share (S_i) are derived through the Shephard's (1970) lemma as

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

The translog cost function can be used along with the profit-maximizing condition to generate an additional equation representing the optimal choice of the endogenous output (Q) (Fuss and Waverman, 1981, pp. 288-289).

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[7] The six districts are Taipei, Hsinchu, Taichung, Tainan, Kaohsiung, and Taitung and the five size classes are 1 (less than 0.5 hectares), 2 (0.5-0.75), 3 (0.75-1.0), 4 (1.0-1.5), and 5 (1.5 and over). The details are to be explained in the next section.

Taking the derivative of the cost function (5) with respect to the endogenous output Q, we have

$$\frac{\partial \ln C}{\partial \ln Q} = \frac{\partial C}{\partial Q}\frac{Q}{C} = \frac{PQ}{C}$$

where P is the price of output [8]. Denoting PQ/C as S_Q, the revenue share equation can be written as

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

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

Including the revenue share equation in the estimation of the system of equations will in general lead to more efficient estimation of the coefficients, in particular, of the output-associated variables due to an additional information provided by the revenue share [9].

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 neutrality of technological change with respect to the stock of technological knowledge R and output scale Q are not imposed a priori. Instead, these restrictions can be statistically tested in the process of estimation of this function. The following three hypotheses concerning the production technology will be tested in this study.

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

Second, Hicks-neutral technological change in the variable factor inputs with respect to the stock of technological knowledge R is tested by imposing the restrictions, $\mu_{iR} = 0$ $(i = L, I, K)$.

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[8] In this case, the rice farmer is assumed to equate the marginal revenue to the government-supported rice price, since the output price P includes the government subsidy payments.

[9] For a detailed discussion on the inclusion of the revenue share equation in the system of regression equations, see Ray (1982) and Capalbo (1988).

Third, neutrality of technological change with respect to output scale Q is tested by imposing the restrictions, $\delta_{Qi} = 0$ $(i = L, I, K)$.

As exposed later, the test results of the last two hypotheses are intimately related to the pure bias effect and the scale bias effect of technological change as defined by Antle and Capalbo (1988).

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):

$$\sigma_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j} \qquad i,j = L, I, K. \qquad i \neq j \tag{8}$$

$$\sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} \qquad i = L, I, K. \tag{9}$$

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

$$\epsilon_{ii} = S_i \sigma_{ii} \qquad i = L, I, K. \tag{10}$$

$$\epsilon_{ij} = S_j \sigma_{ij} \qquad i,j = L, I, K. \qquad i \neq j \tag{11}$$

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:

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

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

$$\varepsilon_{CQ} = \frac{\partial \ln C}{\partial \ln Q} = \alpha_Q + \sum_{i=1}^{3} \delta_{Qi} \ln P_i + \gamma_{QQ} \ln Q + \delta_{QB} \ln Z_B + \mu_{QR} \ln R \qquad i = L, I, K. \tag{13}$$

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

$$\varepsilon_{CB} = \frac{\partial \ln C}{\partial \ln Z_B} = \beta_B + \sum_{i=1}^{3} \theta_{iB} \ln P_i + \delta_{QB} \ln Q + \theta_{BB} \ln Z_B + \beta_{BR} \ln R \qquad i = L, I, K. \tag{14}$$

3.2 IMPACTS OF THE STOCK OF TECHNOLOGICAL KNOWLEDGE

First, the impact 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.

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

Second, the bias effects of the stock of technological knowledge, if any, can be captured by the non-neutral changes in the variable 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 (16) can be expressed as

$$B_i^e = \frac{\mu_{iR}}{S_i} + \frac{\delta_{Qi}}{S_i}\left(-\frac{\varepsilon_{CR}}{\varepsilon_{CQ}}\right) \qquad (17)$$

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

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

If neutrality of technological change with respect to output scale exists, which implies $\partial \ln S_i / \partial \ln Q = 0$, i.e., $\delta_{Qi} = 0$ for all $i(= L, I, K)$, then 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) 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 [10]

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

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

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

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.

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[10] 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).

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), and the quantity of land as a fixed input. 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 classified in the SRRPC. The five size classes are (1) less than 0.5, (2) 0.5-0.75, (3) 0.75-1.0, (4) 1.0-1.5, and (5) 1.5 hectares and over. The six districts are Taipei, Hsinchu, Taichung, Tainan, Kaohsiung, and Taitung. Thus, the sample size is $18(years) \times 5(classes) \times 6(districts) = 540$.

Several points are worth mentioning here about the agricultural districts and the sampling procedure of the SRRPC. First, agricultural "district" is used for an area with climatically similar characteristics and in general covers wider areas than prefectures. Taipei district is composed of Taipei and Yilan prefectures; Hsinchu district is composed of Taoyuan, Hsinchu, and Miaoli prefectures; Taichung district is composed of Taichung, Changhwa, and Nantou prefectures; Tainan district is composed of Yunlin, Chiayi, and Tainan prefectures; Kaohsiung district is composed of Kaohsiung and Pingtung prefectures; and Taitung is composed of Taitung and Hwalien prefectures. These six districts cover more than 95 percent of the total rice production in the Province of Taiwan. The most important districts are Hsinchu, Taichung, and Tainan which shared 80.4 percent of the total rice production in, say, 1993.

Second, the survey is conducted by sampling about 530 rice farms for the six districts in each year. In 1993, for example, 528 rice farms were sampled; 52, 112, 115, 118, 75, and 56 farms were assigned to Taipei, Hsinchu, Taichung, Tainan, Kaohsiung, and Taitung. It seems that these sample numbers reflect the shares of production of these six districts in the total rice production. Furthermore, the distribution of the samples, 528, among the six size classes were 125 for class 1, 158 for class 2, 71 for class 3, 109 for class 4, and 65 for class 5, indicating a fairly even sampling. These tendencies in the sampling procedure were consistent over time, although the latter sort of distribution is not given for each district.

One can compile each pooled data set separately for the first and second crops. The first crop is produced during March through June and the second crop during July through October. The second crop needs a shorter time because it includes summer time with high temperature. The total quantities of production of both the first and second crops have been declining; they were 1.38 and 1.27 million metric tons in 1976 and declined to 1.05 and 0.77 million metric tons in 1993 in terms of brown rice. The quantity of production of the second crop used to be slightly greater than that of the first crop until around the late-1960s. Since then, however, the share of the first crop in the total rice production became greater than that of the second crop; it increased from 54 percent in 1971 to 58 percent in 1993. The harvested areas have been fairly equal between the first and second crops. Thus, the major difference in the total quantities of production between the first and second crops comes from the difference in the yields per hectare of the two crops. Although the yields of the two crops increased consistently over time, the absolute levels of them have been in favor of the first crop; the yields of the first and second crops increased from 3,863 and 3,017 kilograms in 1976 to 4,947 and 4,310 kilograms in 1993, respectively. This study utilized the data set for the first crop [11].

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 weighted average of the government purchasing prices ($N.T. per kilogram) for the Japonica and Indica rice. The total revenue ($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* (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 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. In the following paragraphs, all 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

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

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. Needless to say, in measuring the quantity and price of labor as above, we are assuming perfect substitutability both between male and female labor and between family, hired, and contract labor.

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. However, 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) which is treated as a fixed input, the planted area was used. It is 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 the procedure proposed by Ito (1989, pp.12-13). The necessary data for the expenditures on agricultural R&E 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 [12]. 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 over-estimation of the stock of technological knowledge. Thus, the evaluations of the estimated results will entail qualifications. The R&E expenditure data were deflated by the GNP deflater in order to construct the stock of technological knowledge [13].

Now, the stock of technological knowledge is determined by the annual 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 lag structure and the obsolescence rate for the Taiwanese rice sector, this study simply 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

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[12] In general,it is extremely difficult to compile the data for R&E expenditures on individual products due to lack of information. One could still estimate the R&E expenditures and hence the stock of technological knowledge specifically for rice production by, say, using the share of the Taiwanese rice production in the total agricultural production as a weight. A careful scrutiny reveals that the value share of rice production in the total agricultural production decreased steadily from 32.6 percent in 1976 to 14.8 percent in 1993. However, because budgetary changes by the government often take a long time due mainly to vested interests, it may not be realistic to assume that the share of the R&E expenditures on rice production in the total agicultural R&E expenditures has been declining as fast as that of rice production to total agricultural production. Instead, it may be more realistic to consider in such a manner that, though limited, there may be certain amount of spillovers from the R&E activities in other crop (and even livestock) production. Another difficult problem about R&E activities is that administration often eat up a considerable part of these expenditures and thus the R&E expenditures do not directly associate with the actual investment in technological knowledge. Nevertheless, R&E activities may not be efficiently carried out without administration. It may thus be justified to regard the sum of the expenditures on R&E and administration activities as a composite variable for R&E activities. Thus, the basic data for the whole agricultural sector collected by Shih, Fu, and Chen were used as they are with no processing.

[13] The appropriate deflater such as the deflater for R&E expenditures in agriculture are not available at present.

rice sector by Ito [14]. In this sense also, the estimated results of the present study will have to be evaluated with qualifications.

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.

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[14] This assumption may not be that irrelevant considering the fairly similar basic technological system of rice production in Taiwan and Japan, although there exist climatical differences between the two countries. In the personal interviews, several research people in experiment stations both in Taiwan and in Japan agreed on the acceptability of this assumption. As for the lag structure, however, Alston, Norton, and Pardy (1995, pp. 29-31) recommend to introduce a 30-year lag structure for research, development, and adoption. Nevertheless, even though it may be an ideal procedure, in order to apply such a long lag structure, one needs to go further back in the history to obtain the data on the expenditures on R&E activities, which is often very demanding and difficult to execute.

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 [15]. 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 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 N.T. dollars at the 1986 prices.

Although this study uses farm-firm average 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 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 and concavity conditions. Thus, this option was used for the stock of technological knowledge R in the present study.

5 STATISTICAL METHOD

For statistical estimation, since the quantity of output(Q) on the right hand side of the translog 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

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[15] This assumption is based on personal interviews with extension people both in Taiwan and in Japan.

function (5), two of the three cost share equations (6) [16], and one revenue share equation (7). Note here that the estimating model as a whole is complete in the sense that it has as many (four) equations as endogenous variables (four). The method chosen was thus the full information maximum likelihood (FIML) method. 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 THE HYPOTHESIS TESTINGS AND FINAL SPECIFICATION OF THE COST FUNCTION

For the tests of the three hypotheses, i.e., (1) constant returns to scale (CRTS), and (2) Hicks neutrality and (3) scale neutrality of technological change with respect to the stock of technological knowledge, a Wald Chi-square test was applied. The computed Chi-square statistics for these three hypotheses were 5.2, 628.8, and 871.6 with the degrees of freedom, 7, 3, and 3, respectively. The critical values at the 0.05 and 0.01 significance levels for the degrees of freedom 7 and 3 are 14.6 and 7.8, and 18.4 and 11.3, respectively. Thus, the hypotheses of Hicks neutrality and scale neutrality were strongly rejected both at the 0.05 and at the 0.01 significance level. However, the hypothesis of CRTS could not be rejected both at the 0.05 and at the 0.01 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 [17].

In addition, the joint null hypothesis of no regional differences in the intercept (H_0 : $d_{Rk} = 0$ for all $k = 2,3,4,5,6$) was tested and strongly rejected. Furthermore, the coefficients of all the regional dummy variables had fairly large asymptotically computed t-values, indicating statistical significance of them. A casual examination of the coefficients of these dummies tells us that Hsinchu, Taichung, Tainan, and Kaohsiung districts had lower total cost than Taipei district, while Taitung district showed higher total cost than Taipei district [18]. On the other hand, the joint null hypothesis of no size differences in the

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[16] Due to the linear-homogeneity-in-prices property of the cost function, one factor share equation can be omitted from the simultaneous equation system for the statistical estimation. In this study, the capital share equation was omitted.

[17] This result is consistent with that of Kuroda (1997) 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.

[18] These tendencies and the magnitudes of the coefficients are almost the same before and after the

intercept ($H_0 : d_{Sl} = 0$ for all $l = 2, 3, 4, 5$) was not rejected. Indeed, the asymptotically computed t-values of all the size dummy coefficients were less than unity, indicating that they are not statistically significant.

Thus, the system of equations (5), (6), and (7) were re-estimated with an additional imposition of the parameter restrictions of CRTS and no size effects on the intercept. The coefficients of the omitted (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 0.928, 0.745, 0.631, and 0.646 for the variable cost function, labor share equation, intermediate-inputs share equation, and revenue share equation. Furthermore, except for only a few coefficients, the computed t-statistics are fairly large, indicating that the estimated coefficients are statistically significant except for a few coefficients. Thus, it can be said that the goodness of fit is considerably good. This set of estimates is referred to as the final specification of the model and will be used for further analyses [19].

6.2 FACTOR DEMAND AND SUBSTITUTION ELASTICITIES

Factor demand elasticities with respect to factor prices as well as the Allen partial elasticities of substitution (AES) were computed at the geometric means and are reported in Tables 2 and 3, respectively. The following two findings are noteworthy in the tables.

First, the own-price elasticities of demand for labor, intermediate inputs, and capital are all less than unity in absolute values, i.e., 0.348, 0.376, and 0.485, respectively, indicating inelastic demand for these factor inputs by farm-firms. However, the demand elasticity for capital is the largest among the three elasticities in absolute values. 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 changes in the prices of labor and intermediate inputs.

Second, the AESs between labor and intermediate inputs, labor and capital, and intermediate inputs and capital are 0.264, 0.786, and 0.729, respectively. This indicates that labor and intermediate inputs are not good substitutes, but labor and capital, and intermediate inputs and capital are fairly good substitutes [20].

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re-estimation of the system with the imposition of CRTS restrictions and no size dummies to be discussed next.

[19] Monotonicity and concavity were also checked and satisfied not only at the geometric means but also at all the sample observations. Furthermore, due to the parameter restrictions for constant returns to scale, i.e., $\alpha_Q + \beta_B = 1$, $\delta_{Qi} + \theta_{iB} = \delta_{QB} + \theta_{BB} = \gamma_{QQ} + \delta_{QB} = \mu_{QR} + \beta_{BR} = 0$ ($i = L, I, K$), SCE estimated using equations (12), (13), and (14) was unity for all the sample observations.

[20] These results on the elasticities of the factor demand and substitution are very similar to those obtained using the parameter estimates of the variable cost function where the time variable was used as

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 for each year of the 1976-93 period. 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 5. Recall here that Figure 1 presents for the Taipei district the rates of technological change which had been already 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 (Kuroda 1997).

At least, two important features are noteworthy in Figures 1 and 5. First, the rate of technological change given in Figure 1 were classified into four trends (Kuroda 1997): (1) it increased sharply from around 2.5 to 3.3 percent for the 1976-80 period; (2) it then slowed down from 3.3 to 2.8 percent for the 1980-1986 period; (3) it increased sharply again from 2.8 to 4.0 percent for the 1986-89 period; and (4) it appears to have started declining again for the 1989-93 period, from 4.0 percent in 1989 to 3.3 percent in 1993, although the rates were still greater than 3 percent. These rates of technological change may be said to be considerably 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. 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 Figure 5, one can observe very similar movements in the negative of the cost-R&E elasticities for the same study period. That is, (1) the cost reduction effects of the R&E capital stock increased sharply from around 0.23 to 0.28 during the mid-1976-80 period; (2) it then slowed down to 0.24 in 1986; (3) it increased sharply again from 0.24 in 1986 to 0.33 in 1989; and (4) it appears to have started declining again for the 1989-93 period. 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. Furthermore, abandonment and diffusions of cultivation of marginal paddy fields along with the rapid decrease in the planted area during the study period must have been

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an index of technological change (see Kuroda, 1997, Tables 2 and 3).

another factor which helped raise the yield per hectare of the paddy field utilized for rice production and hence gave positive effects on the cost reducing performance of the R&E activities.

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 the 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 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 0.32 in 1976 to around 0.57 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 0.45 to 0.67. This finding is consistent with the rapid increase in the utilization of chemical-fertilizers and agri-chemicals for rice production in Taiwan. It may be intriguing to note that the general movements of the intermediate-inputs-using bias is very similar to that of the negative of the cost-R&E elasticity $(-\varepsilon_{CR})$ shown in Figure 5. This may indicate that so-called bio-chemical (BC) type technological change which in general raises yields per hectare must have been a dominant factor to determine the movements of the cost reducing effect of the stock of technological knowledge during the period 1976-93.

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 0.45 in 1976 but consistently slowed down to 0.25 in 1993. This finding is consistent with the rapid mechanization in the Taiwanese rice production during the late 1970s and the pace-down or stabilization 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 Hicksian 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 N.T. dollars per million N.T. 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, it was found that the larger the size class, the greater the MPs. However, the differentials of the MPs among size classes became smaller and smaller over time; the MPs of the lower four size classes were around 0.3 to 0.8 N.T. dollars per million N.T. dollars of the stock of technological knowledge in 1993. Second, the MPs of all the size classes other than the largest size class decreased consistently over the 1976-93 period. On the other hand, although the MP of the largest size class decreased sharply until 1989, it appears to have an increasing trend after that and hence the differentials in the MPs between the largest size class and the other size classes seem to be widening. What are the causes for such differentials in the MPs between the largest class and the other classes? To answer this question, it is convenient to go back to equation (18). It was found that there exist only slight differentials in the magnitudes of the $(-\varepsilon_{CR})$s among the five size classes in all the six districts. Furthermore, it was found there exist constant returns to scale in the Taiwanese rice sector, which implies the 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 differentials in the MPs come mainly from the differentials in the levels of output. This result may thus indicate 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 the nominator nMP in equation (19) to yield the *social* IRR to the stock of technological knowledge in the Taiwanese rice sector [21]. Assuming the period of investment returns T to be infinity and the lag of diffusion θ to be five years in equation (19) [22], the estimated *social* IRR turned out to be 37 percent [23]. 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 37-percent IRR for the

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[21] This average nMP is naturally over-estimated by the following two critical reasons. First, the shares of larger-sized farm-firms are much smaller than those of smaller-sized farm-firms. However, 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.

[22] 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.

[23] Under the assumption that the 70 percent of the total Taiwanese farm households were rice producers for the 1976-93 period, the IRR turned out to be 31 percent.

Taiwanese rice sector is much higher than the per annum market interest rate for one-year time deposits which was 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.

This conclusion should further be qualified because of the following two reasons other than the reasons related to the lack of data of the numbers of rice-producing farm households in the different size classes. First, the data of the expenditures on R&E activities employed in this study might have understated the costs by omitting or underestimating overhead costs. Second, we may have overestimated the *IRR* because we have failed to count the effects of private-sector R&D or spillovers of technology from other places, from foreign countries or international institutions such as the International Rice Research Institute.

7 SUMMARY AND CONCLUSIONS

Using the translog variable cost function framework, this study investigated quantitatively the impacts of the public *R&E* activities on the production structure of the Taiwanese rice industry for the 1976-93 period . The 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.

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 1997).

4. The cost reduction effects of the R&E capital stock (1) increased sharply during the mid-1976-80 period; (2) it then slowed down until 1986; (3) it increased sharply again during the 1986-89 period; and (4) it appears to have started declining again for the 1989-93 period. 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 1997). This indicates 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, 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. In addition, abandonment and diffusions of cultivation of marginal paddy fields along with the rapid decrease in the planted area during the study period must have been another factor which helped raise the yield per hectare of the paddy field utilized for rice production and hence gave positive effects on the cost reducing performance of the R&E activities.

5. The cost reduction effects of the public R&E activities were almost equal among the five different size classes in all the six districts for the study period, indicating that the technological diffusions were neutral irrespective of size classes in the Taiwanese rice sector.

6. 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 Hicksian induced innovation theory.

7. 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 was caused mainly by the larger outputs per unit of the stock of technological knowledge in larger-sized rice producers. 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 more efficiently the stock of technological knowledge, a larger scale farming is more desirable for the Taiwanese rice sector.

8. The social *IRR* of the stock of technological knowledge was 37 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.

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 the production and costs of 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 also holds 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 information for the latter at present. As mentioned earlier, no arbitrary procedure was applied in order to estimate the R&Es 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 are also weak due to lack of data on these aspects. Due to these shortcomings related to data, therefore, the results of this paper have to be qualified substantially and taken as preliminary. For the follow-up study, a better data set should be developed by overcoming these shortcomings.

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Table 1: FIML Estimates of the Translog Variable Cost Function for the Taiwanese Rice Sector with the Imposition of the CRTS Restrictions, 1976-93 (First Crop)

Parameter	Coefficient	t-statistic	Parameter	Coefficient	t-statistic
α_o	10.809	548.5	θ_{BB}	0.650	33.0
α_Q	1.619	222.3	δ_{QL}	-0.202	-19.0
α_L	0.410	158.1	δ_{QI}	0.127	19.2
α_I	0.222	170.1	δ_{QK}	0.074	8.1
α_K	0.367	7.2	δ_{QB}	-0.651	-33.0
β_B	-0.619	-35.9	μ_{QR}	0.010	1.6
β_R	-0.315	-22.9	μ_{LR}	-0.140	-21.1
γ_{QQ}	0.651	14.2	μ_{IR}	0.053	9.1
γ_{LL}	0.099	9.4	μ_{KR}	0.089	10.2
γ_{II}	0.089	10.2	β_{BR}	-0.010	-0.6
γ_{KK}	0.054	3.8	β_{RR}	0.021	0.5
γ_{LI}	-0.067	-10.1	d_{R2}	-0.203	-9.3
γ_{LK}	-0.032	-14.1	d_{R3}	-0.212	-9.9
γ_{IK}	-0.022	-1.6	d_{R4}	-0.206	-6.8
θ_{LB}	0.202	11.1	d_{R5}	-0.151	-6.5
θ_{IB}	-0.127	-10.3	d_{R6}	0.059	2.9
θ_{KB}	-0.074	-8.1			

Estimating Equations	$\bar{R}^2$
Cost function	0.928
Labor share equation	0.745
Intermediate inputs share equation	0.631
Revenue share equation	0.646

Table 2: Demand Elasticities with Respect to Factor Prices

	Labor	Intermediate Inputs	Capital
Labor Price (P_L)	-0.348	0.059	0.289
	(-54.9)	(18.4)	(5.6)
Intermediate Inputs Price (P_I)	0.108	-0.376	0.267
	(18.4)	(-6.1)	(3.5)
Capital Price (P_K)	0.322	0.162	-0.485
	(23.5)	(4.3)	(-9.5)

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

Table 3: Allen Partial Elasticities of Substitution

	Labor	Intermediate Inputs	Capital
Labor	-0.847	0.264	0.786
	(-54.9)	(18.4)	(23.5)
Intermediate Inputs		-1.691	0.729
		(-6.1)	(4.3)
Capital			-1.319
			(-4.5)

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

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

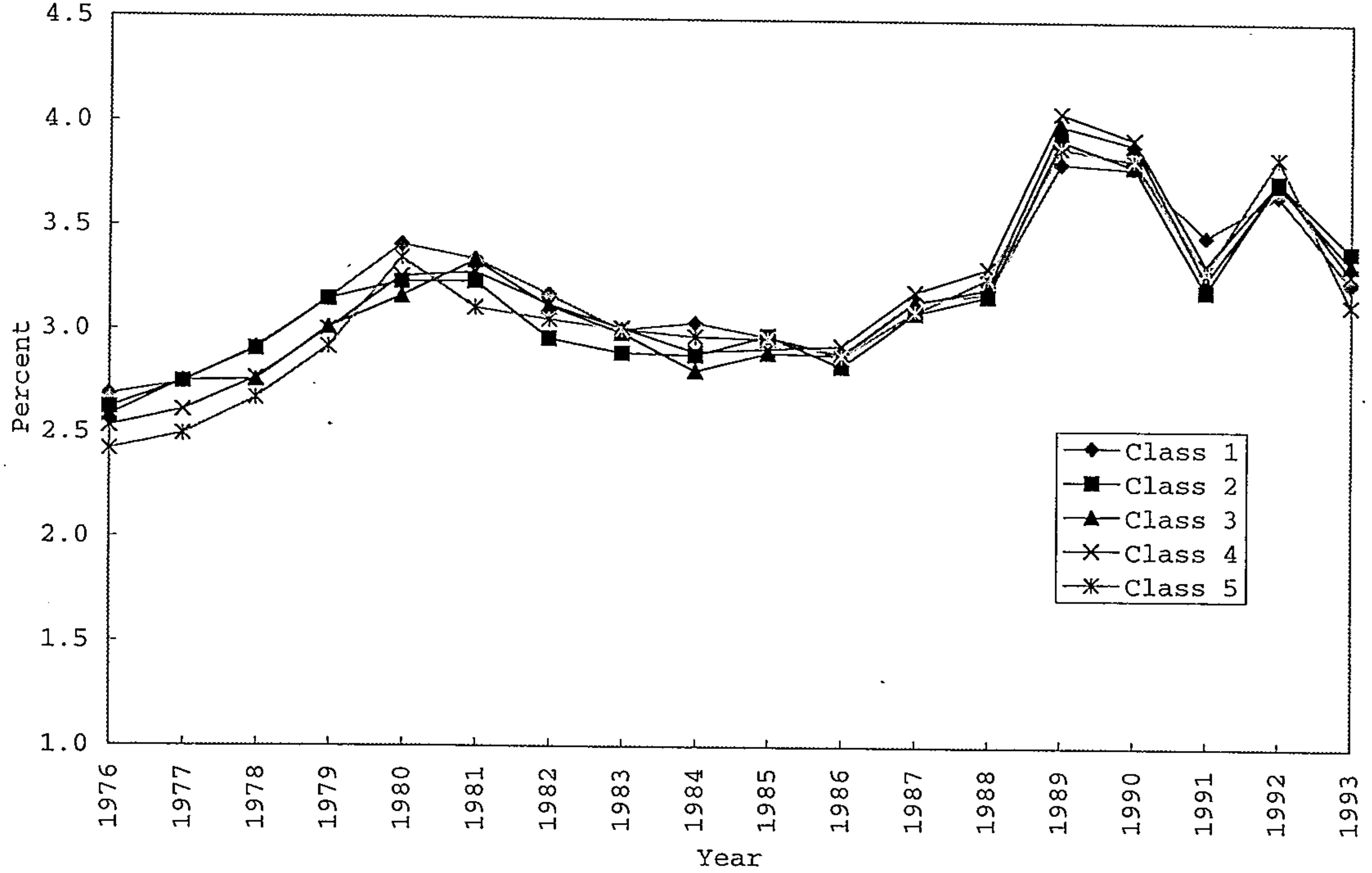
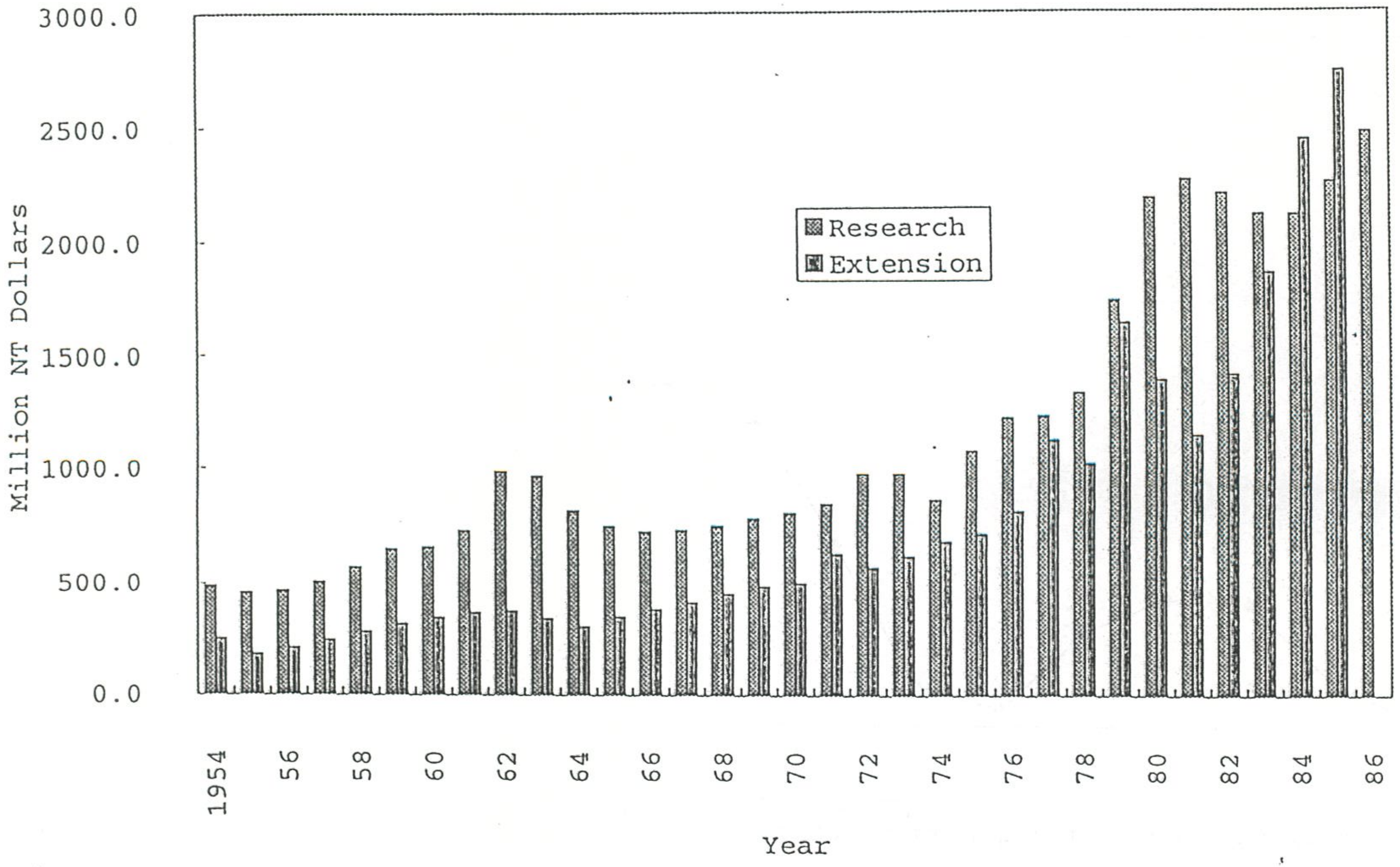
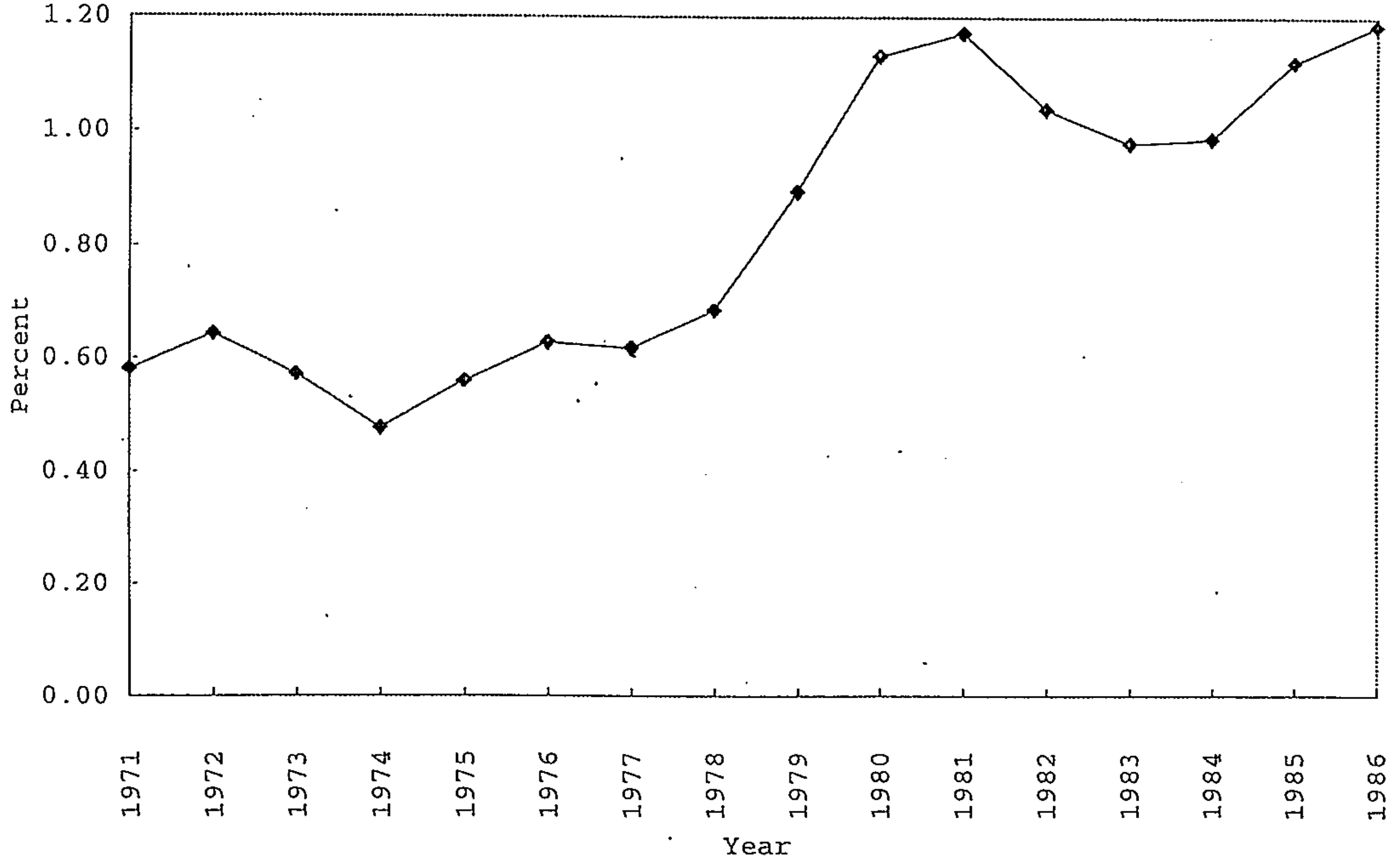


Figure 2. Public Research and Extension Expenditures for the Agricultural Sector, 1954-86 (In Million NT Dollars at 1986 Prices)



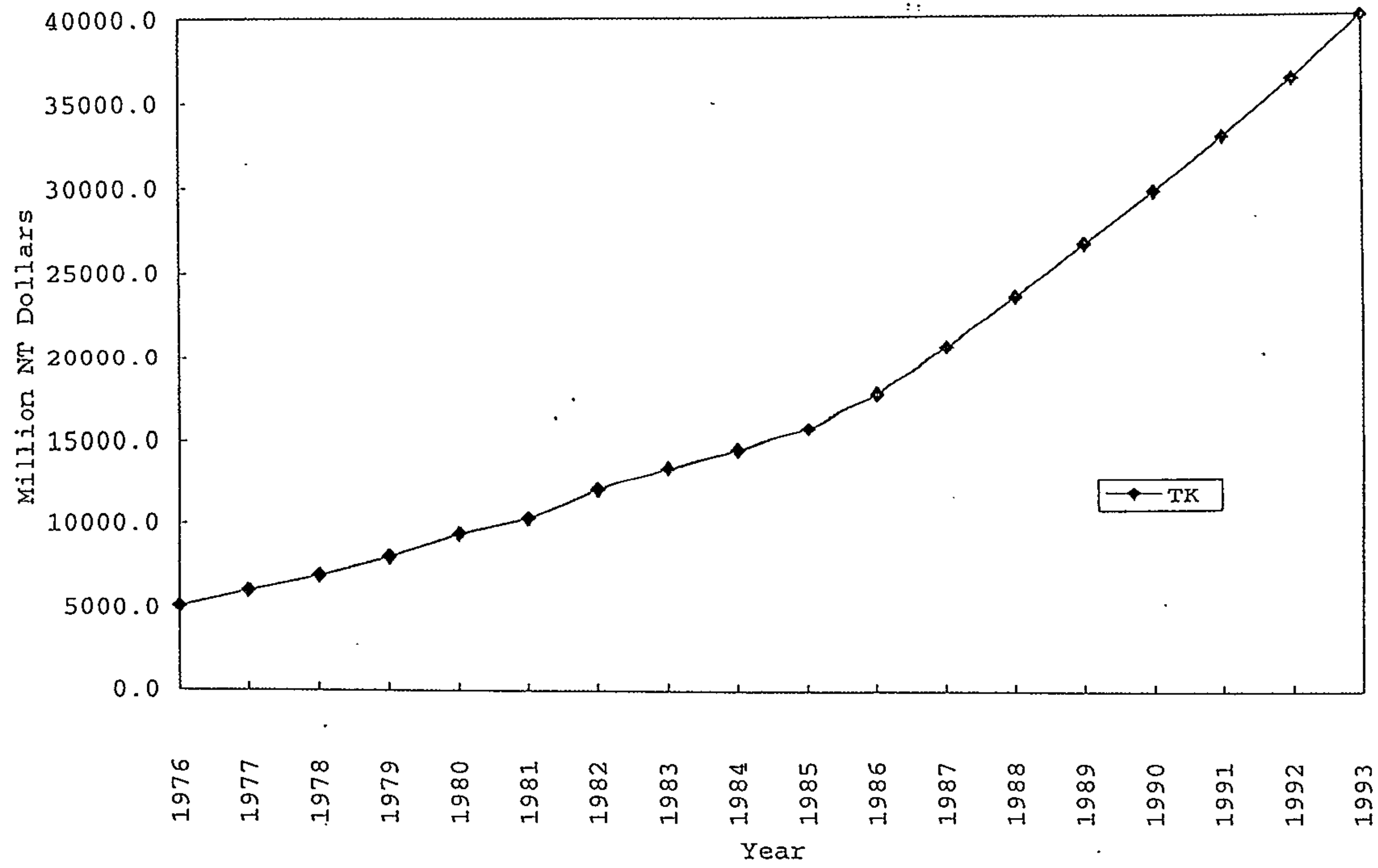
Source: Shih, J.T., Fu, T.T., and Chen, C.H. "Returns to the Investments in Agricultural Knowledge in Post World War II Taiwan," *Academia Economic Papers*, Vol. 18, No.2 (September 1990). (In Chinese).

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



Source: 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).

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



Source: 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).

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

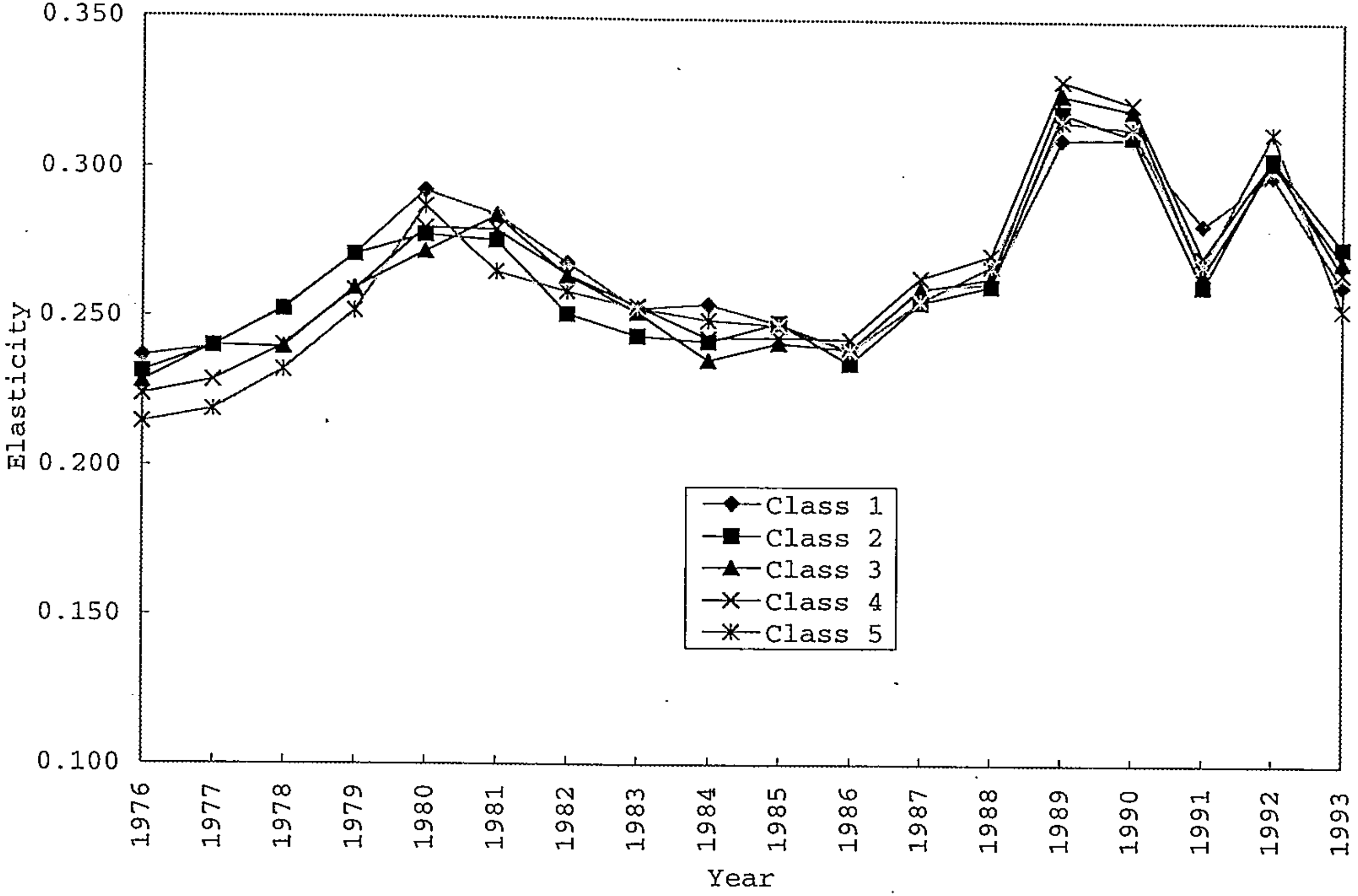


Figure 6. Labor Bias w.r.t. the Stock of Technological Knowledge, 1976-93: Taipei (In elasticity)

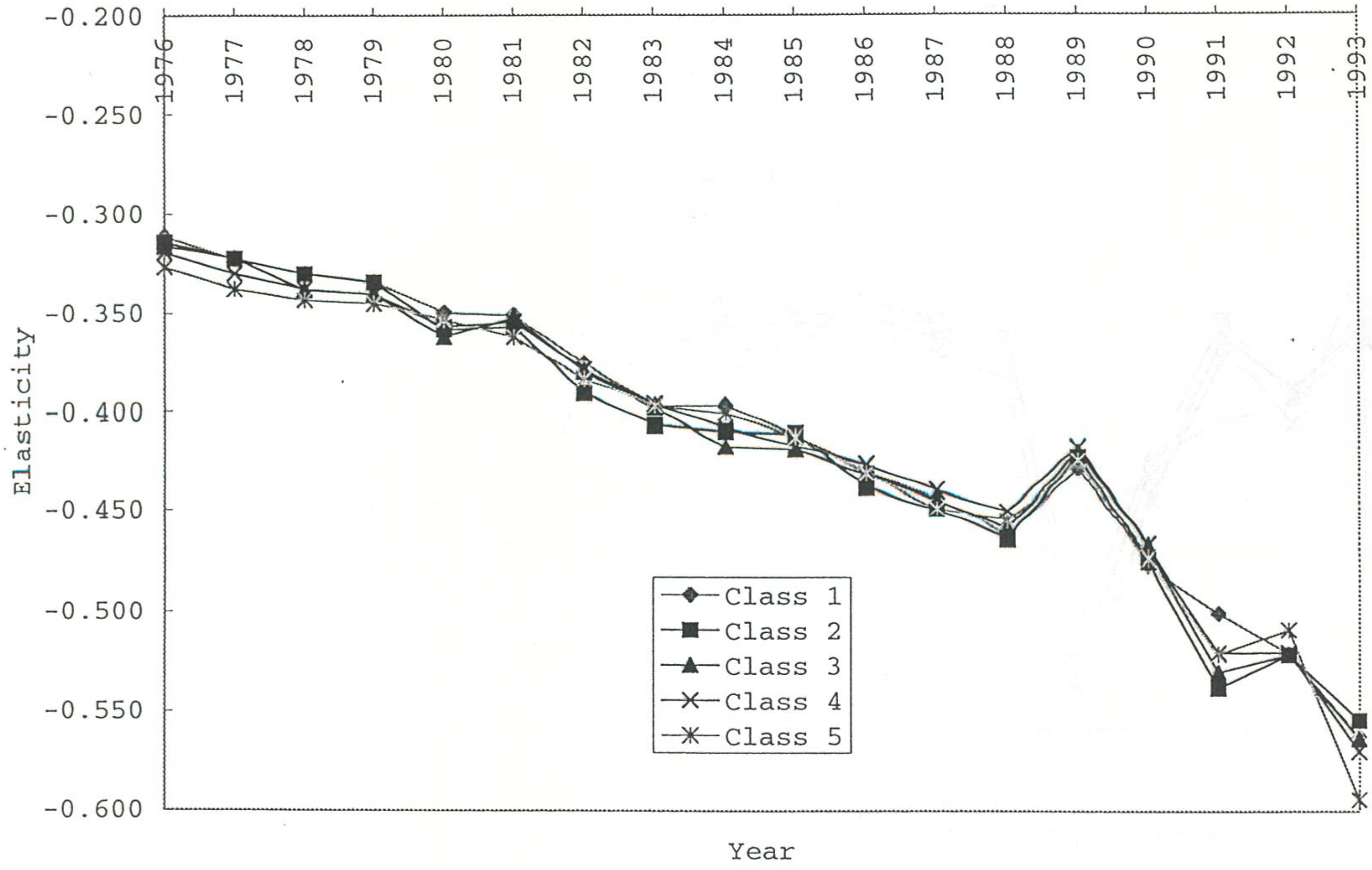


Figure 7. Intermediate-Inputs Bias w.r.t. the Stock of Technological Knowledge, 1976-93: Taipei (In elasticity)

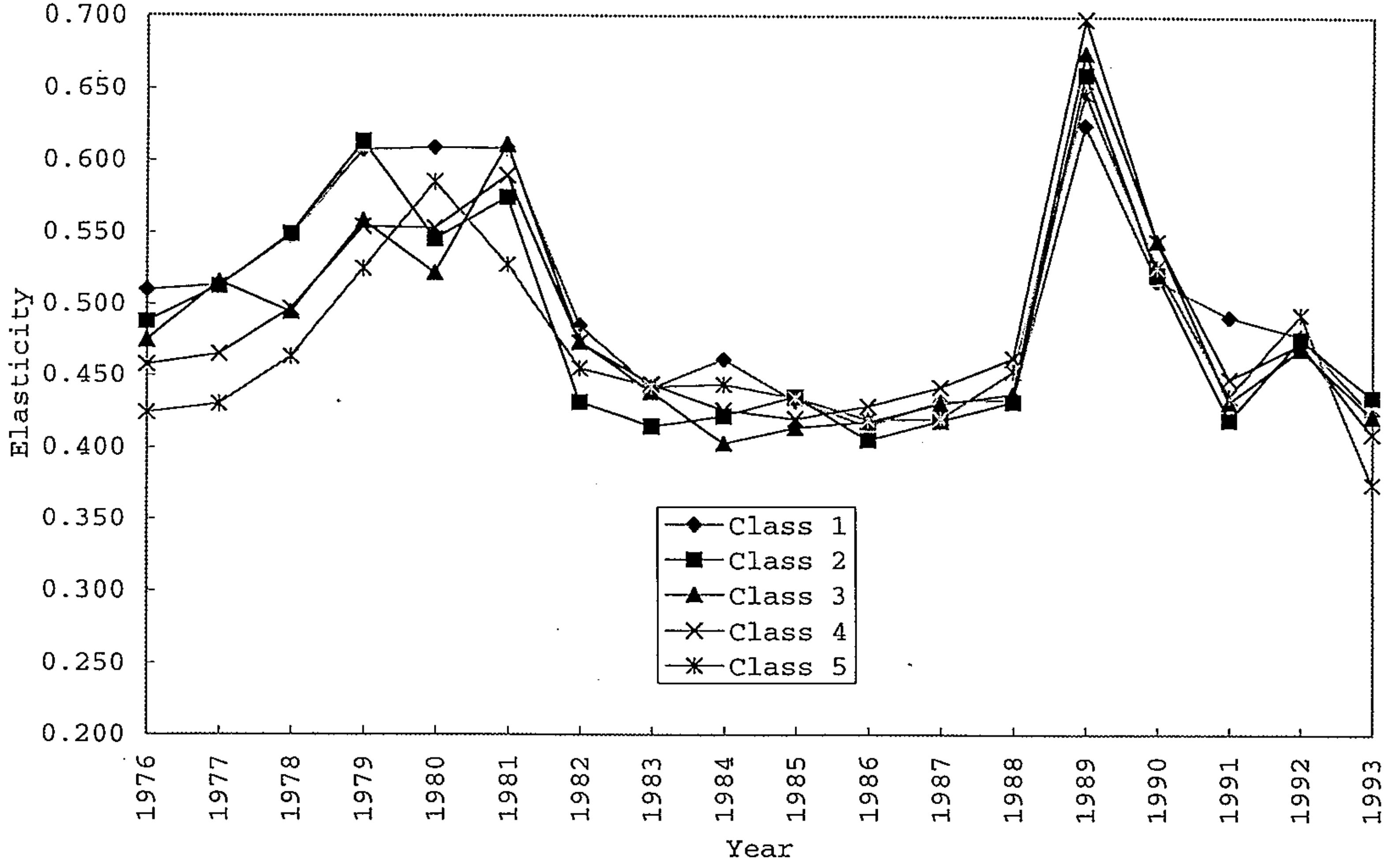


Figure 8. Capital Bias w.r.t. the Stock of Technological Knowledge, 1976-93: Taipei (In elasticity)

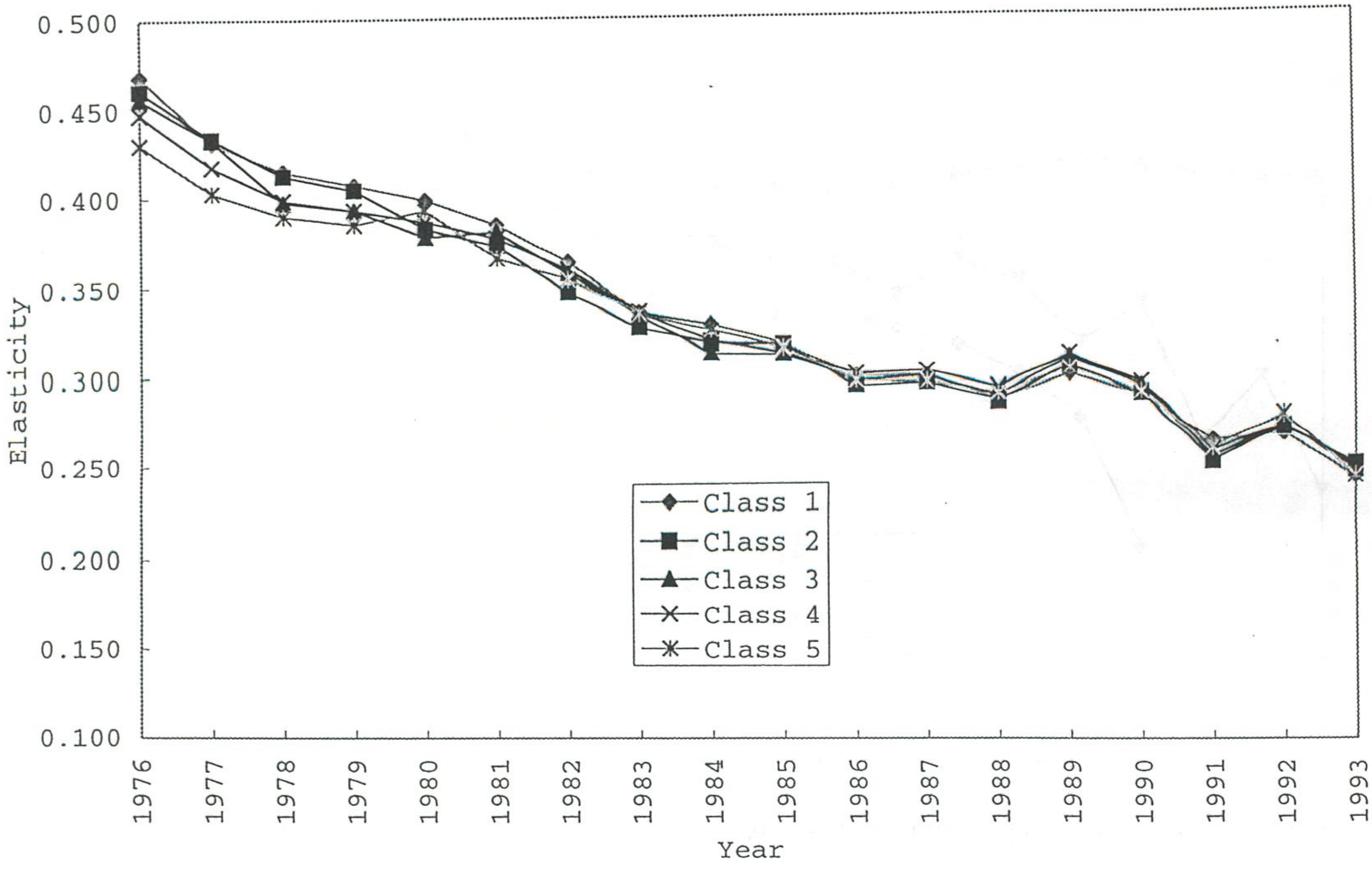


Figure 9. Factor Prices, 1976-93: Taipei, Class 1 (Taipei-Class-1-1976=1.0)

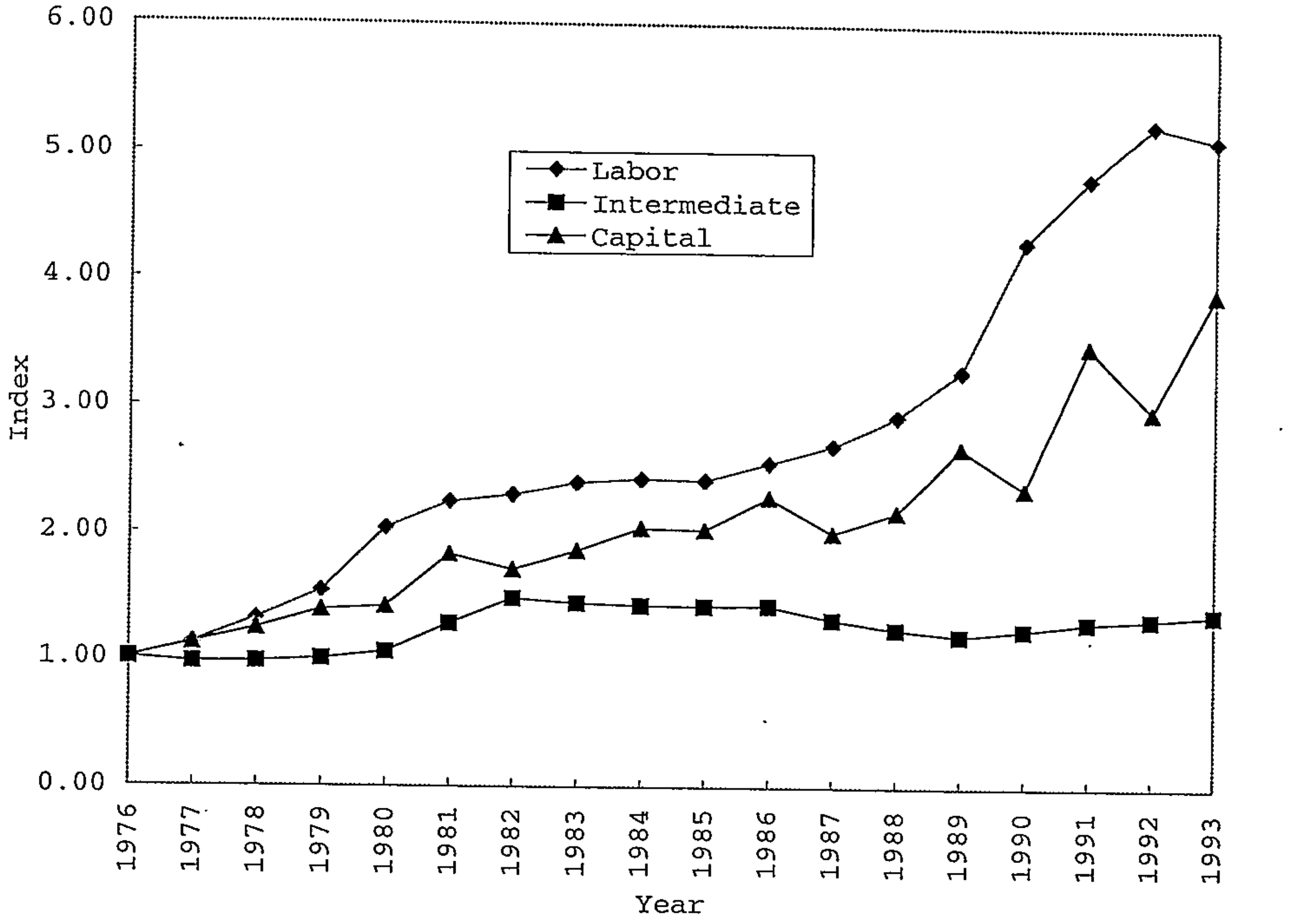


Figure 10. Shadow Price of the Stock of Technological Knowledge (STK), 1976-93: Taipei (In $N.T. per $Mil. N.T. of the STK)