Assessing Returns to R&D Expenditures on Post-War Japanese Agricultural Production

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Abstract: The objective of this paper is to disentangle the question of the influence of R&D investment on resource allocation efficiency and income distribution in Japanese agriculture during 1960–87. The average marginal product of R&D stock as estimated by the cost function approach is calculated to be 4.47 at 1985 prices and 1.84 at current prices, and the internal rates of returns are 45.6 percent and 33.9 percent. In spite of their high profit-earning efficiency, they have drawn near to the profitability criterion, the current interest rate. Although technical progress induced by R&D activities increases social welfare without fail, its distribution among consumers and producers depends, to a large extent, on market circumstances. The empirical results suggest that consumer and producer economic surpluses have collided with respect to the allocation of R&D investment.

Introduction

Since R.M. Solow shed some light on the contribution of technical progress to economic growth, two kinds of economic themes have been assigned to economists. One is to test the validity of the induced innovation hypothesis and another is to highlight the source of technical progress. Even in the area of agriculture, numerous empirical studies have been undertaken on the former subject, and it seems to be generally accepted that they uphold the validity of the induced innovation hypothesis. For the latter, Griliches (1988) and Akino (1973), in compliance with Schultz's hypothesis, proposed that R&D and rural education are major contributors to technical progress, and they assessed R&D profitability by means of production function analysis.

Attempts to pin down the efficiency of R&D investment, however, have not always succeeded, and much still remains open for further empirical studies. The significance of economic analysis of this subject is in the following two directions. First, as large parts of agricultural research activities are assigned to the public sector, the incentives for the pursuit of profit are likely to be weakened. As a result, the efficiency of R&D activities is liable to be inhibited. The economic implications are thus likely to arouse the concern of not only economists but also investment decision makers. Second, since technical knowledge, apart from ordinary private goods, has a public good attribute, it is hard to grasp its imputed price as evaluated in the market, which finally gives rise to market failure. These two characteristics of agricultural research will probably impede efficient R&D activities.

This paper has two main objectives. The first is to calculate the internal rate of return (*IRR*) of R&D investment in Japanese agriculture during 1960–87. The second is to elucidate how the economic surplus yielded by technical progress is distributed among consumers and producers.

The analytical framework is in line with previous studies, developed in terms of: (1) the source of technical progress is regarded not so much as R&D investment but rather as R&D knowledge stock; (2) in calculating the marginal product of R&D stock, the cost function approach is employed instead of the conventional production function (for the cost function approach to R&D profitability, see Stranahan and Shonkwiler, 1986, and Ito, 1991); and (3) the marginal product of R&D stock evaluated in the market is estimated, taking explicit account of an attribute of technical knowledge as a public good.

R&D and Extension Activities

Before proceeding with the empirical study, some brief background on research and extension activities adopted in Japan after the second World War is in order. In view of price differences between substantial products both within and outside the country, development of technology that makes it possible to lower production costs is an urgent priority for Japanese agriculture. In this situation, the national research institutes have set out to promote basic research by investing half the amount of R&D expenditure in it and 300 local research institutes have been striving to meet location-specific technical demands. Local institutes' research expenditures currently amount to 2.3 times those of the national institutes.

Figure 1 shows the change in the ratio of R&D investment to the agricultural budget and output after 1950. In spite of a fairly steady improvement in the ratio of R&D expenditures to agricultural output, it is now no more than 0.7–0.8 percent. Given that this ratio ranges from 2–3 percent in other industries, it may be said that investment in agricultural R&D is inadequate.

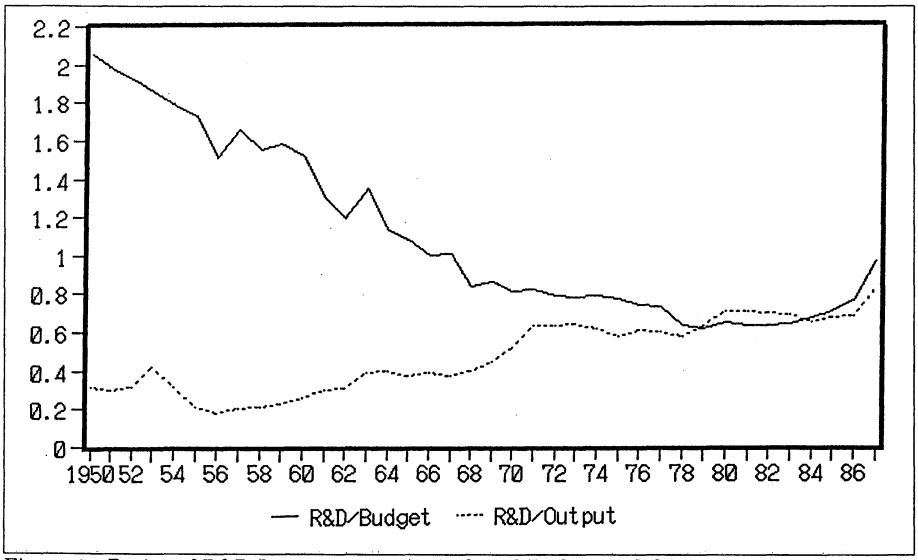

Figure 1—Ratios of R&D Investment to Agricultural Budget and Output (percent)

Empirical Model and Data

Model

Previous empirical studies that estimated the marginal product of the R&D knowledge stock are based on total factor productivity (TFP) analysis, assuming a linear homogeneous production function. For all its simplicity, this method fails to measure the contribution of R&D to productivity increase, on the grounds that TFP includes the effect of technical progress as well as that of nonconstant returns to scale (Capalbo, 1988). On the other hand, the cost function approach paves the way for relaxing the restriction of linear homogeneous production technology.

The dual expression of the marginal product of R&D knowledge stock assessed in the market ($\partial F/\partial R$) can be written as:

$$(1) \quad \frac{\partial F}{\partial R} = \Sigma\Sigma_{ij} n_{ij} \frac{\partial f^{ij}}{\partial R} = \Sigma\Sigma_{ij} n_{ij} \frac{\partial C^{ij}/\partial R}{\partial C^{ij}/\partial Y},$$

where R, Y, and n_{ij} stand for R&D stock, total output, and the number of farm households belonging to the ith region and jth operational size (for calculation of the shadow price of fixed inputs from the cost function, see Diewert, 1974). Since technical knowledge has a characteristic of a public good, its imputed price will be evaluated by aggregating the individual ones.

The cost function $C^{ij}=C^{ij}(P, Y; R; Y)$, which has R&D stock as a factor input, is specified in the translog form as follows:

$$lnC^{ij} = \alpha_0 + \Sigma\alpha_i lnP_i + \beta_y lnY + \beta_r lnR + \beta_s lnS + \Sigma_i\alpha_{iy} lnP_i lnY + \Sigma_i\alpha_{ir} lnP_i lnR + \Sigma_i\alpha_{is} lnP_i lnS$$
$$(2) \quad + \beta_{yr} lnYlnR + \beta_{rs} lnRlnS + \frac{1}{2}\{\Sigma\Sigma_{ij}\alpha_{ij} lnP_i lnP_j + \beta_{yy}(lnY)^2 + \beta_{rr}(lnR)^2 + \beta_{ss}(lnS)^2\}$$

where P_j S denote the input price and farmland ($j = l$ for labour, m for machinery, and i for intermediate goods). After deriving the cost share equations by applying Shephard's lemma to the cost function, Zellner's iterated seemingly unrelated regression methods are used for parameter estimation.[2]

Data

If technical knowledge is permitted to be treated as an ordinary tangible asset, data related to the gestation period of investment and depreciation rate of capital stock, as well as those on investment expenditure, are needed for stock estimation. For the former, the average gestation period of research, 6 years, as recorded in the "Annual Report of Research Institutes of the Ministry of Agriculture, Forestry, and Fisheries," is assumed to represent the time lag for R&D payoffs, while the efficient period for a research outcome can be identified as the obsolescence rate of R&D stock. Investigation has shown that the R&D knowledge stock is subject to an annual rate of depreciation of 10 percent. On the basis of these data, R&D stock is estimated by the bench mark year method.

Empirical Results

Internal Rate of Return

Figure 2 illustrates the change in the marginal product of representative farms for each operational size in Tokyo and other prefectural areas at 1985 prices. They increased until the end of the 1960s, and declined thereafter, while maintaining a positive correlation with farm size. Assuming technical knowledge as a divisible factor input, the marginal product of each farm is regulated by its operational size.

The legitimacy of the cost function approach can be ascertained by comparing the change in the marginal product with technical progress. In concrete terms, applying Diewert's quadratic lemma to the translog cost function, technical progress can be calculated as a residual (Diewert, 1978).[3] Results indicate that the rate of technical progress has a consistent trend with the change in the marginal product of R&D stock, which attests the validity of the cost function approach.

Figure 3 depicts the change in the aggregated imputed price of R&D stock; its average value is computed to be 4.47 at constant prices and 1.84 at current prices. And the corresponding *IRR(r)* are 45.6 percent and 33.9 percent, given by:

$$(3) \quad \exp(r\theta) = \int_0^\infty (\partial F/\partial R)(-rt)dt,$$

ion,where θ represents the diffusion lag (assumed to be 5 years). After the 1980s, during which the marginal product drastically declined, the marginal product of R&D stock has come close to the profitability criterion of the interest rate.

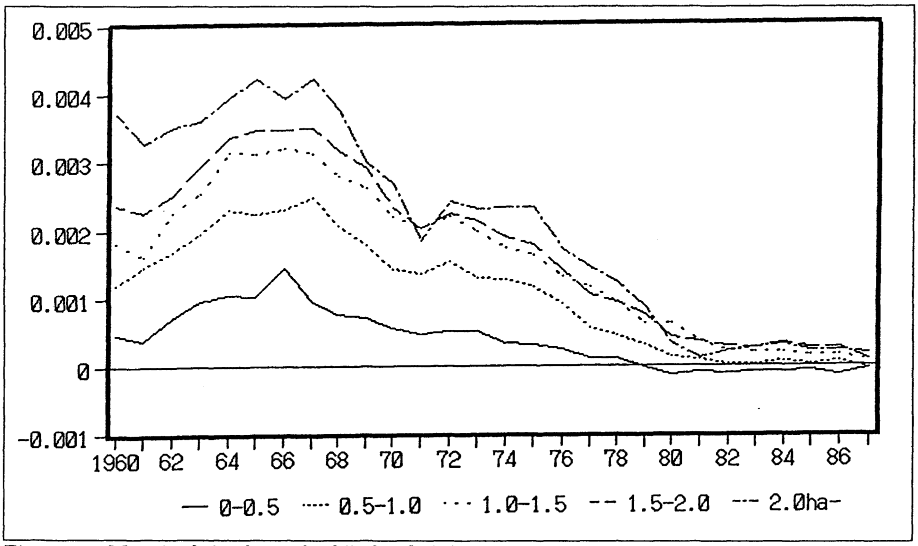

Figure 2—Marginal Product of R&D Stock (1/1000 ¥, 1985 constant prices)

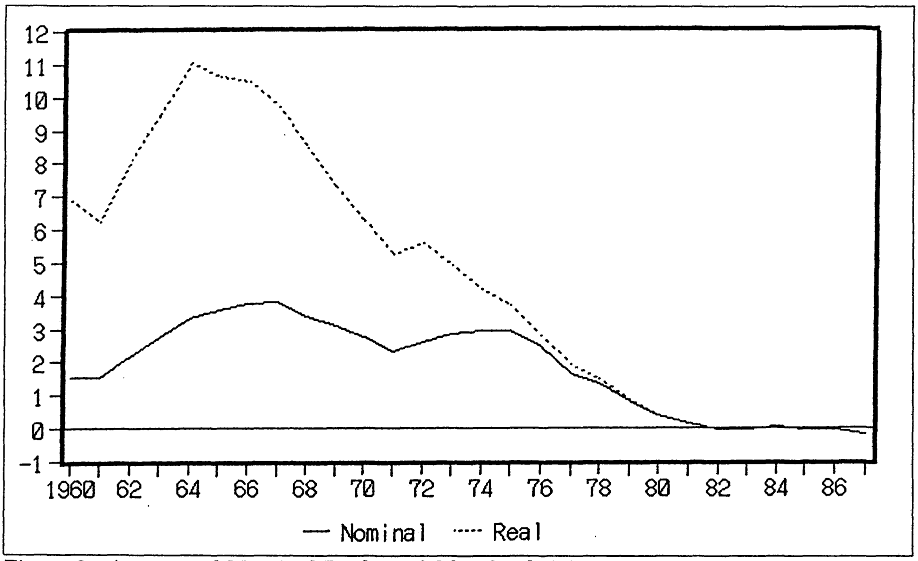

Figure 3—Aggregated Marginal Product of R&D Stock (¥)

The Distribution of Economic Surplus

The paper now moves on to the second aspect of interest, investigation into the impact of R&D on consumer and producer welfare. As is intuitively understood, a marginal increase in R&D stock brings about a rightward shift of the supply curve of agricultural product; as a result, social welfare certainly increases. However, its distribution among consumers and producers depends to a large extent on the circumstances of the agricultural product market. To be more concrete, some parts of economic surplus yielded by technical progress will revert to consumers through a decrease in product prices, while others due to producers will be contingent on the balance of cost reduction and price decline.

To clarify this, de Gorter and Zilberman's theoretical model (1990) was used. Since the equilibrium price and output in the agricultural market are a function of R&D stock (R), consumer utility (V) and producer profit (π) are also functions of R, and if R&D stock is determined by government in such a way as to maximize consumer utility (or producer profit), $\partial V/\partial R$ (or $\partial \pi/\partial R$) is equal to zero.[4] Figure 4 discloses the change in the partial differentiation of V and π with R&D stock. To the extent that they are positive, R&D investment is insufficient for the respective economic agent, and vice versa. This figure indicates that an additional R&D stock would raise consumer welfare for the period under question, and before 1976 it would also raise producer surplus. Therefore, at least for 1960–76, a marginal provision of R&D input would constitute Pareto improvement. However, from then on there is no feasible allocation of R&D investment where everyone is at least as well off and at least one agent is strictly better off. Accordingly, these results imply that benefits to consumers and producers have recently collided.

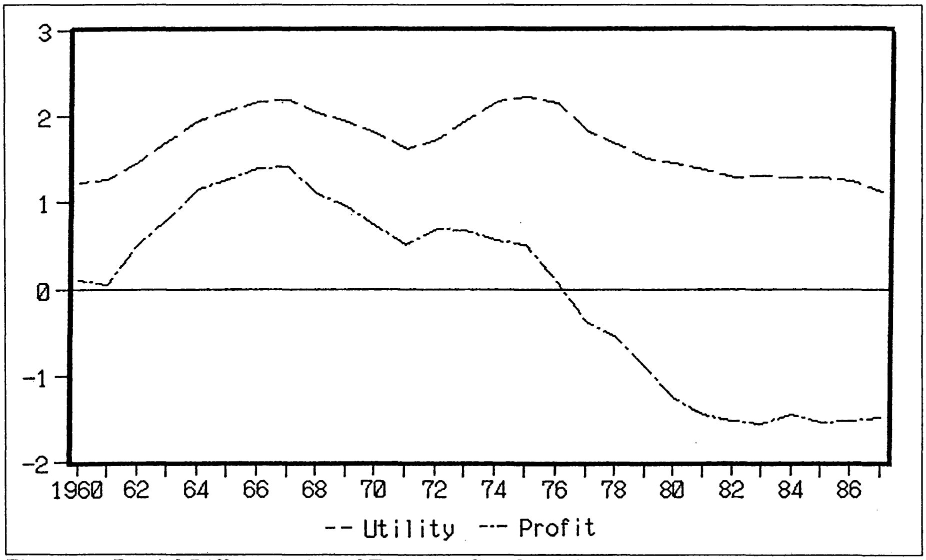

Figure 4—Partial Differentiation of Economic Surplus (¥)

Conclusion

Some concluding remarks may be summarized as follows:

(1) Although the internal rate of return to R&D investment in Japanese agriculture has been sustaining a high level since the 1960s, its has been trending downwards after peaking in the mid-1960s.

(2) The allocation of R&D investment has attained Pareto efficiency since 1976.

(3) Generally speaking, consumers (producers) cannot become better off without a welfare loss to producers (consumers), which implies that the government is under heavy popular pressure to draw up an appropriate agricultural research policy.

Notes

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[2]Every regularity condition of the cost function is satisfied at each observation.

[3]Technical progress ($-\partial \ln C/\partial \ln t$) captured as a residual is given by:

$$\frac{1}{2}\left(\frac{\partial lnC}{\partial lnt}+\frac{\partial lnC}{\partial lns}\right)[t-s]=\ln\frac{C_t}{C_s}-\Sigma_j\frac{B_{jt}+B_{js}}{2}\ln\frac{P_{jt}}{P_{js}}-\frac{1}{2}\left(\frac{\partial lnC}{\partial lnY_t}+\frac{\partial lnC}{\partial lnY_s}\right)\frac{lnY_t}{lnY_s}-\frac{1}{2}\left(\frac{\partial lnC}{\partial lnS_t}+\frac{\partial lnC}{\partial lnS_s}\right)\frac{lnS_t}{lnS_s},$$

where subscripts t, s and B symbolize the time and cost share of the jth factor respectively.

[4]The partial differentiation of consumer and producer surplus with R&D stock is expressed as follows:

$$\frac{\partial V}{\partial R} = -\frac{YC_{Y_R}}{1-\eta^D/\eta^S} - i, \text{ and } \frac{\partial \pi}{\partial R} = \frac{YC_{Y_R}}{1-\eta^D/\eta^S} - C_R,$$

where η^D, η^S are price elasticities of demand and supply (de Gorter and Zilberman, 1990), and sufficient conditions of consumer utility and producer profit maximization are satisfied at each observation.

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Discussion Opening—*Yasuhiko Yuize* (Chiba University)

To produce data on the R&D knowledge stock of Japanese agriculture and to measure its returns on agricultural production can be regarded as pioneering, even heroic. While being highly appreciative of the work, I should also like to point out a few problems in application of the theory to the data.

In order to estimate the effects of R&D knowledge stock on production, this study makes use of the cost function instead of the production function. The production function represents the pure technical input-output relationship. On the other hand, the cost function is a derived function, derived from maximizing profit; i.e., determining the equilibrium relationship between the production function and the market prices of products and of inputs as fixed factors. The study needs to be modified by distinguishing three phases of the agricultural situation in the postwar period in Japan: part-time farming, the government acreage allotment, and land improvement capital.

Part-Time Farming

Part-time farming is managed as a balance between farm income and nonfarm income, but not only within farm jobs. For instance, farm machinery is often overinvested to save farm labour and to increase nonfarm labour in a farm household. Also, farm households generally use marginal or fringe labour, particularly aged labour, which is not supplied to the labour market to determine the wage rate. Therefore, the marginal productivities of the machinery and labour inputs may lose their equilibrium with the price of machinery and the market wage rate.

The Government Acreage Allotments after 1970

This administrative power may have skewed input-output relations in farm production. The farm price of rice has not always been consistent with the cropping area of rice because of government policy, and not always with current inputs because of subsidies. Therefore, the marginal productivities of current inputs may not have balanced with their prices.

Land Improvement Capital

The land variable in the cost function is adopted as a fixed factor, but it does not include land improvement capital. This is a kind of social capital, which is important to farming, especially to rice production. Capital formation is largely dependent on central and local government expenditures, like those on R&D. So, a little of the price of capital is paid by the farmers. This variable should be considered as a fixed factor in the same way as the R&D knowledge stock. Data on the capital stock of land improvement from 1960–86 in Japan show an S-shaped curve, which is similar to that of the R&D knowledge stock. If this capital stock instead of the R&D stock were involved in the cost function, the estimation might have brought out almost the same results as in this study.

[Other discussion of this paper and the author's reply appear on the following page.]

General Discussion—*Steve McCorriston, Rapporteur* (University of Exeter)

Questions addressed issues relating to both definitions used and points made by the presenters. Tanaka asked Shigeno to distinguish between the term "Noka" ("farm-attached household") commonly used in Japan and the term "farm household" that is frequently used in English translation. Shigeno agreed that one has to be careful in drawing a distinction between the definitions of farmer, farm household, and family farming, his definition being those "engaged in farming." Schmitt asked Tsuboi to clarify "successors," since many "successors" may participate in part-time farming, which may contradict the author's view concerning the future decline of family farming in Japan. Tsuboi's response was that his evidence only dealt with full-time farmers. Schmitt also addressed the first paper by questioning whether the economic determinants of aged farmers to supply labour differed from those affecting the labour force in nonfarm activity.

In dealing with the comments made by the discussion opener, Shigeno justified his observation of low opportunity cost of aged family labour in Japan by arguing that labour market frictions and other factors (such as the Japanese family system) prevented exit from farming. He nevertheless agreed that further research incorporating both economic and cultural factors is necessary, his study only dealing with the former. Tsuboi was not fully convinced by the discussant's view that smaller farms may be more damaging to the environment relative to large. Ito's response to his discussant focused on the effect of government land policies on R&D efficiency. In principle, he argued, the effects of government land policies could be empirically established by disaggregating his results, which could be done in future research, though he doubted whether it would affect his overall conclusion.

Participants in the discussion included Y. Tanaka (University of Tsukuba) and G. Schmitt (Universität Göttingen).