「레이 동조 확률 생산함수」에 의한 경영규모별 미곡생산의 효율성 분석

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Farm Size and Production Efficiency of Korean Rice Farms: An Application of a Ray-Homothetic Stochastic Production Function

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초록

이 연구는 한국 쌀생산의 효율성을 경영규모별로 파악하고, 영농규모 확대를 통한 쌀생산의 효율성 증대가 가능하다는 가설을 검정해 보고자 하였다.

이 분석에 필요한 기술적 선도농가들의 생산함수인 프런티어(frontier) 생산함수를 구하기 위해서는 교란항의 정보를 이용할 수 있는 확률(stochastic) 모형이 바람직하고, 아울러 경영규모별로 규모의 효율성을 파악하기 위해서는 레이 동조(ray-homothetic) 함수가 적절하다. 따라서 여기에서는 농림수산부의 1992년도 쌀생산비 자료에서 임의로 추출한 1,203호의 표본 자료를 이용해 앞에서 언급한 두가지 요소를 동시에 감안할 수 있는 「레이 동조 확률 생산함수(ray-homothetic stochastic production function)」를 최우추정법(Maximum likelihood estimation method)으로 추정하였으며, 이를 토대로 쌀생산의 경영규모별 비효율성을 순수 기술적 비효율성과 규모의 비효율성으로 나누어 계측하였다.

계측결과에 의하면 쌀생산의 비효율성은 평균 36.1%에 이르고 있다. 이 가운데 순수 기술적 비효율성은 12.0%이고, 규모의 비효율성은 24.1%에 달했다. 기술적 비효율성과 규모의 비효율성 모두 경지규모 확대와 더불어 감소하는 것으로 나타나, 경영규모 확대와 더불어 미곡생산의 효율성이 증대될 수 있다는 가설은 기각되지 않았다. 그러나 대농의 경우에도 규모의 비효율성이 여전히 높은 것으로 나타나 영농규모 확대를 저해하는 제도적 장벽이 아직도 높다는 것을 알 수 있다. 아울러 대농과 소농과의 효율성 격차가 현저하지는 않은 것으로 나타나 단순히 경지를 중심으로 한 경영규모 확대만으로는 효율성 제고에 한계가 있음을 보여주고 있다.

이 연구의 결과는 다음과 같은 정책적 함의를 가지고 있다. 첫째, 한국 미곡생산의 효율성 증대 잠재력이 결코 과소 평가되어서는 안된다. 둘째, 영농규모 확대가 쌀생산의 효율성 증대를 위해 필요한 것은 사실이지만 단순한 경지규모의 확대에 치중하는 것보다 영농규모 확대를 저해하는 제도적 기술적 장애요인을 제거해 나가는 것이 더욱 중요하다. 마지막으로, 새로운 영농기술의 개발은 물론이고 현행 선진영농기술의 보급도 쌀생산의 효율성 증대에 상당한 역할을 할 수 있다는 사실이 간과되어서는 안된다.

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I. Introduction

World Trade Organization (WTO) launched in 1995 has brought us the urgent task to enhance production efficiency of Korean agriculture to cope with the trade liberalization of agriclutural products. The Korean government has been undertaking the reformation of agricultural structure, which concentrates on the enlargement of farm size. Despite its efforts of government, it is not likely to be so easy to promote the competitiveness of Korean agriculture since the present agricultural structure faces a difficult situation to be adjusted in the near future.

Especially Korean rice farming is generally operated in extremely small scales, which has been moderately increased for the last 50 years. The rice farm size will not increase rapidly in the near future, either. Moreover, there has been an argument among Korean agricultural economists whether the increase of farm size in rice production can be of help in enhancing the efficiency of production in a semi-subsistant farming society like Korea or not. Most of Korean agricultural economists recommend policy-makers to increase the size of rice farming because they believe that small farms are relatively inefficient or unprofitable in a competitive environment. On the other side, the others support that small farms are superior to large farms with regard to the efficient use of resources. Even the results of the foreign studies are varied as the data sets they employed. Lau and Yotopoulos(1971) found that the small farms were more profitable than larger farms in their sample farms of India. But Hall and LeVeen(1978), Garcia, Sonka and Yoo(1982) and Bagi and Huang(1983) found no difference in the profitability of small and large farms. But Aly, et al. (1987) and Byrnes, et al. (1987) found that large farms were more profitable than small farms.

Many previous studies showed that there existed the economy of scale in Korean rice production (Kwon, 1985; Kim & Ryu, 1986; Chung, 1993; Chun, 1994; Hong, 1994). However, the increasing returns to scale in rice production does not necessarily imply that the production efficiency is improved with the enlargement of farm size. The economy of scale is measured in terms of the proportional change in output as all inputs are varied in fixed proportion. Therefore the increasing returns to scale implies that the increasing rate of output is greater than that of inputs in fixed proportion.

When production thechnology changes considerably as farming size increases, we can not expect the fixed proportional change of all inputs. Therefore it is more useful to know how production efficiency changes with farm size than to know what the economy of scale is. Especially efficiency indicators by farm size are very useful to reform the structure of rice production in Korea since farming technology changes rapidly as the farm size increases. But only few studies on such a topic have been done in Korea. Using the cost data of rice production in 1987, Lee and Cho(1990) found that the efficiency of input usage is improved as farm size increases. And Lee(1986) attempted to measure an allocative efficiency under tenancy of rice production, which is indirectly related to the relationship between efficiency farm size.

This paper aims to measure the extent of technical efficiency among a sample of Korean rice farms by farm size using a ray-homothetic stochastic frontier production function and to test a hypothesis that efficiency of rice production can be increased through the enlargement of farm size.

II. Methodology

Economic efficiency is essential for a firm to survive under economic uncertainty. The economic efficiency can be expressed in several ways. A popular measurement of economic efficiency is a ratio of output to inputs used. However, Farrel(1957) established the measurement of economic efficiency in a relative sense as a deviation from the best performance in a representative of sample. The economic efficiency can be classified into technical and allocative efficiency. The technical efficiency includes pure technical and scale efficiency.

The technical inefficiency occurs when less than maximum output is obtained from a given set of inputs. Untiming, improper application of production factors and inadequate farm management result in the pure technical inefficiency. The operation in an inappropriate scale causes the scale inefficiency. Allocative or price inefficiency takes place when an equilibrium condition that the ratio of marginal products of inputs equals to the ratio of market prices of inputs fails.

There are various methods to measure and compute technical efficiency. Most are related to both the construction of a best-practice frontier and the measurement of inefficienecy from the frontier. A formulation of frontier needs to estimate a representative production function.[1] We can illustrate a production technology as a set, or production function. The production set approach is proper for the multiple inputs and multiple outputs. The production technology is mostly expressed with functional form, from which the relationship between inputs and outputs is specified. The production function approach is suitable for one output and multiple inputs and useful for the analytical purpose (McFadden, 1978). The direct estimation of production function using inputs and outputs is very difficult because such physical data are usually unobtainable. Also, it is not so easy to get the relevant price data of inputs and outputs from farmers. But aggregate economic data such as expenditures and returns can be easily obtained from the production cost survey data.

The farm production function can be estimated by two different approaches; frontier

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1) Without estimating a production function, we can measure the frontier by the non-statistical methods (i.e. deterministic parametic or non-parametric methods), mostly linear programming algorithm (Farrel, 1957; Färe, et al, 1985). This approach, however, has a drawback of no allowance made for environmental heterogeneity, random external shocks, measurement error, etc. (Aly, et al., 1987).

and average fitted production functions. The frontier production function approach among them is more pertinent to the analysis of production efficiency.

A frontier production function specifies input-output relationship to obtain the frontier output, i.e. the maximum output obtainable with the technology of frontier farmers from a given level of inputs under the socio-economic condition they are confronted with (Seitz, 1970). Therefore, frontier output is different from the output that can be obtained from the average fitted production function (hereafter, production function). The frontier output can be obtained by plugging input levels into the frontier production function. This is a maximum output that can conceively exist and embody the current technology (Førsund, et al., 1980).

The methods used for the estimations are deterministic statistical frontiers and stochastic frontiers. The deterministic statistical frontier is estimated by a statistical method assuming a functional form for the frontier (see more details, Timmer, 1971; Afriat, 1972; Richmond, 1974; Greene, 1980). The popular way to estimate the frontier is the use of a corrected ordinary least squares regression (COLS). The production functional form is first estimated using ordinary least square regression, and then the constant term is moved until no residual is positive and at least one is zero. Thus, the inefficiency of a particular farm is measured by the ratio of actual output to frontier ouput, which lies on the frontier (Rusell and Young, 1983; Aly, et al., 1987).

Using the deterministic frontier method, the estimation of production function and the construction of frontier are not so difficult, but several problems are remained. Although the error term includes random external shocks and measurement error as well as technical inefficiency, all deviations from the frontier are considered as technical inefficiency. Thus, the measurement of technical inefficiency can be biased.

Unlike the deterministic approach, the stochastic frontier method introduces two different disturbance terms (Just, et al., 1978; Olson, et al., 1980). One represents noise, measurement error, and exogenous shocks beyond the control of the production farm. The other involves the technical inefficiency. So the pure technical inefficiency can be distinguished from other disturbances. In this study to measure production inefficiency of Korean rice farms, therefore, the stochastic statistical frontier is estimated using a maximum likelihood method (Lee, 1983).

The pure technical inefficiency is obtained under the assumption that the socio-economic conditions at a specific year are given. So it does not include the scale inefficiency. The scale inefficiency can be calculated with the stochastic frontier production function and the scale equation derived from the parameters of the stochastic frontier production function and the intensity of input use.

III. Model and Data

Some previous studies on the specification of frontier production function (Aigner and Chu, 1968; Afriat, 1972; Schmidt, 1975) could not have methodological justifications, because the statistical method that they used violates the regularity conditions of maximum likelihood. Subsequently, more appropriate specification of stochastic error term was proposed for the stochastic frontier (Aigner, Lovell, and Schmidt, 1977, hereafter, ALS; Meeusen and van den Broeck, 1977) and generalized distribution (Stevenson, 1980; Greene, 1980).

Given T individual farmers, the stochastic production function model for observation t is written as:

$$(1)\quad y_t = f(X_t, \beta) + \varepsilon_t, \{t = 1, 2, \ldots, T\},$$

where y_t is output obtained by farmer t, X_t is vector of inputs for farmer t, β is vector of parameters to be estimated, and ε_t is error term for farmer t.

Following the ALS (1977) and Stevenson (1980), we specify the revenue function such that error term, ε_t, of the revenue function is $\varepsilon_t = \nu_t - \eta_t$, where ν_t is a shock related to weather and natural disaster out of farmer's control. The ν_t is assumed to be symmetric ($-\infty < \nu_t < +\infty$) using normal distribution (Greene, 1980; Stevenson, 1980). The other error component η_t captures the technical inefficiency, and is truncated such that $\eta_t \geq 0$. The term η_t measures the shortfall of output y_t from its frontier value given by the stochastic frontier, $f(X_t, \beta) + \nu_t$. The stochastic production function can identify the technical inefficiency from other sources of disturbance beyond the farmer's control.

The error terms ν_t and η_t are assumed to be independent of each other. The two error terms are also assumed to be independent of physical inputs x, since management practices of rice farmer directly included in the production can cause a simultaneous equation bias (Mundlak, 1961).

Frontier production function can be estimated with either corrected ordinary least square (COLS) or maximum likelihood estimation (MLE). The estimates obtained by COLS are asymptotically consistent. However, the distribution of η_t has to be asymmetric for the specification. An MLE can include the information of various probability density functions. Thus, the MLE using the information of distribution is more efficient in an econometric sense than the COLS (Greene, 1980; Stevenson, 1980).

In this study, an MLE is used to estimate the stochastic frontier model. Since there is *a priori* no theoretical and empirical basis on the use of specific distribution of η_t, its distribution is assumed to be half-normal $(0, \sigma^2_\eta)$ here. Assuming that ν_t is i. i. d. $N(0, \sigma^2_\nu)$ and is independent of η_t, the sum of two variances of disturbances becomes the variance of ε_t, i. e., $\sigma^2_\varepsilon = \sigma^2_\nu + \sigma^2_\eta$. Let λ be the ratio of the standard error of σ_η to the standard error of σ_ν, i. e., $\lambda = \sigma_\eta / \sigma_\nu$. The likelihood function of stochastic frontier function can be written as:

$$(2)\quad \ln\,[y_t|\beta, \lambda, \sigma^2_\varepsilon]$$

$$= T \ln \sqrt{(2/\pi)} + \sum_{t=1}^{T} \ln\left[1 - F^*\left\{\frac{\lambda\varepsilon_t}{\sigma_{tright}}\right\}\right] - \frac{1}{2\sigma^2_\varepsilon}\sum_{t=1}^{T}\varepsilon_t^2$$

where $\varepsilon_t = y_t - X_t \beta$.

The parameters β, λ, and σ_ε^2 can be estimated from the above likelihood function. The maximum likelihood estimates of the parameters are calculated numerically through the algorithm of nonlinear optimization by setting the derivatives of the parameters equal to zero.

In order to examine the individual sample period, it is convenient to use the method of conditional pure technical inefficiency developed by Jondrow, et al. (1982). Year-specific technical pure inefficiencies are obtained by using the conditional mean of η_t:

$$(3)\quad E(\eta_t|\varepsilon_t)$$

$$= \sigma^* \, [f^*(\lambda\varepsilon_t/\sigma_\varepsilon) \;/\; (1 - F^*(\frac{\lambda\varepsilon_t}{\sigma_\varepsilon}))] - (\frac{\lambda\varepsilon_t}{\sigma_\varepsilon})$$

where f^* and F^* are respectively standard normal density (pdf) and cumalative distribution function (cdf), and $\lambda = \sigma_\eta / \sigma_v$ and $\varepsilon_t = \nu_t - \eta_t$ as defined before.

A scale equation is derived from the frontier production function in order to measure the scale inefficiency (see more details Aly, et al., 1987). The function coefficient (ξ) to determine the returns of scale can be measured with the following equation:

$$(4)\quad \xi = \sum_{i=1}^{n} \frac{\partial y}{\partial x_i} \frac{x_i}{y}$$

Solving output(y) from equation (4),

$$(5)\quad y = \frac{1}{\xi} \sum_{i=1}^{n} \frac{\partial y}{\partial x_i} x_i$$

The optimal output(y_t^o) of individual farm is relevant to its scale optimum in the long-run. Substituting the 'constant returns to scale' condition ($\xi_t^o = 1$) into equation (5) yields the optimum output. Hence, the scale inefficiency(τ_t) of individual farm can be calculated as follows:

$$\begin{aligned}(6)\quad \tau_t &= \frac{y_t^o}{y_t} - 1 \\ &= \left(\frac{1}{\xi_t^o} \sum_{i=1}^{n} \frac{\partial y}{\partial x_i} x_{i_t}\right) / \left(\frac{1}{\xi_t} \sum_{i=1}^{n} \frac{\partial y}{\partial x_i} x_{i_t}\right) - 1 \\ &= \xi_t - 1\end{aligned}$$

In the parametric specification of production function, a ray-homothetic production function (Grabowski & Belbase, 1986) is used instead of the unrestricted Cobb-Douglas function used popularly in most frontier approaches. The ray-homothetic function allows for the possibility that returns to scale may vary with ouput. The specification of ray-homothetic production function is presented as follows:

$$\begin{aligned}(7)\quad \ln Y = \; & \beta_o + \beta_{PS} PS' \ln PS + \beta_{CF} CF' \ln CF \\ & + \beta_{PC} PC' \ln PC + \beta_{PE} PE' \ln PE \\ & + \beta_{CM} CM' \ln CM + \beta_{CL} CL' \ln CL \\ & + \beta_{CT} CT' \ln CT + \beta_K K' \ln K + \varepsilon,\end{aligned}$$

where $\varepsilon = \nu - \eta$

$$PS' = \frac{PS}{(PS+CF+PC+PE+CM+CL+CT+K)}$$

$$CF' = \frac{CF}{(PS+CF+PC+PE+CM+CL+CT+K)}$$

$$PC' = \frac{PC}{(PS+CF+PC+PE+CM+CL+CT+K)}$$

$$PE' = \frac{PE}{(PS+CF+PC+PE+CM+CL+CT+K)}$$

$$CM' = \frac{CM}{(PS+CF+PC+PE+CM+CL+CT+K)}$$

$$CL' = \frac{CL}{(PS+CF+PC+PE+CM+CL+CT+K)}$$

$$CT' = \frac{CT}{(PS+CF+PC+PE+CM+CL+CT+K)}$$

$$K' = \frac{K}{(PS+CF+PC+PE+CM+CL+CT+K)}$$

and PS, CF, PC, PE, CM, CL, CT, and K are seed, ferilizer, pesticide, electronic power and fuels, machinery, labor, land, and capital, respectively. Y is the level of production rather than gross revenue, because rice price in Korea is controlled by government and averge output prices received by farms are almost the same. And β_o, β_{PS}, β_{CF}, β_{PC}, β_{PE}, β_{CM}, β_{CL}, β_{CT}, and β_K are the parameters to be estimated.

The frontier production function is obtained by adding the conditional mean of η_t by equation (3) to equation (7). And the scale equation is constructed by using the estimates of parameters in equation (7) and the intensity of input use. The scale equation, i.e., function coefficient(ξ), can be written as:

$$(8) \quad \xi = b_{PS}PS' + b_{CF}CF' + b_{PC}PC' + b_{PE}PE' + b_{CM}CM' + b_{CL}CL' + b_{CT}CT' + b_{M}M'$$

where $b_i's$ are the estimates of parameters ($\beta_i's$) in equation (7). Note that equation (8) shows that the function coefficient depends on the intensity of input use as well as the estimates of parameters.

The stochatic frontier and the scale function are required to know the extent of which the present rice production is technically inefficient by farm size and the degree to which the inefficiency is due to pure technical inefficency or scale inefficency. Once estimating the stochatic frontier function, the pure technical inefficiency can be calculated by equation (3). And the scale inefficiency can be obtained from equation (6) and equation (8).

Data used for frontier production function are obtained from the production cost survey of agicultural products (PCAG), Ministery of Agriculture, Forestry and Fisheries, Republic of Korea. The sample farms are selected randomly from the PCAG data base on 1992 crop year. The number of rice farms are 1204. The variables of expenditure data from PCAG are listed as seed, ferilizer, pesticide, electronic power and fuels, machinery, labor, land, and capital. As mentioned before, one of the objectives of this paper is to examine the relationship between farm size and technical inefficencies. The sample farms are classified into 5 groups based on the tillable acreage; less than o.5ha, greater than 0.5ha but less than or equal to 1.0ha, greater than 1.0ha but less than or equal to 2.0ha, greater than 2.0ha but less than or equal to 3.0ha, and greater than 3.0ha. Table 1 shows the summary of basic statistics of variables used for the estimation.

Table 1. Summary Statistics for a Sample of Korean Rice Farms(1992)

Variable	Unit	Mean	Standard Deviation	Maximum Value	Minimum Value
Y	Kg	6,016	4,535	40,360	882
PS	1,000 won	5.9	4.7	369.4	7.4
CF	1,000 won	152.0	12.4	896.5	12.3
PC	1,000 won	121.7	104.0	742.4	4.1
PE	1,000 won	11.4	16.7	169.1	1.0
CM	1,000 won	198.0	247.7	2,257.2	10.4
CL	1,000 won	1,064.4	708.5	5,846.0	141.0
CT	1,000 won	2,062.0	1,695.7	18,758.0	193.9
K	1.000 won	1,867.4	172.7	1,868.4	24.5

Source : A sample data of the production cost survey of agricultural produts(1992) by Ministery of Agriculture, Forestry and Fisheries

IV. Results of Estimation

Applying the MLE method for the ray-homothetic function, estimation results are presented in Table 2. All of the estimated parameters, β, λ, and $\sigma_\varepsilon^2(=\sigma_v^2+\sigma_\eta^2)$ are statistically significant at a significance level of 99 percent. The estimation results of λ and σ_ε imply that the variation of output due to weather and external shock is smaller than due to tecnological and managerial factors.

Table 2. Maximum Likelihood Estimates of Ray-Homothetic Stochastic Frontier Function

Variable	Coefficient	Std. Error	t-ratio
β_0	-5.1212	0.1049	-48.797
β_{PS}	1.3267	0.0311	42.654
β_{CF}	1.5399	0.0348	44.267
β_{PC}	1.3230	0.0286	46.323
β_{PE}	3.0148	0.1812	16.636
β_{CM}	1.0677	0.0164	65.019
β_{CL}	0.9475	0.0091	104.695
β_{CT}	0.9569	0.0073	131.819
β_K	1.0556	0.0265	39.797
λ	1.1093	0.1553	7.142
σ_ε	0.2036	0.0078	26.214

Log-Likelihood = 471.5851
σ_v^2 = 0.01858
σ_η^2 = 0.02286

Using the estimation results of stochastic frontier and scale function, the technical, pure technical, and scale inefficiencies were calculated. Table 3 shows that the average pure technical, scale, and total technical inefficiency of rice production sample farms in 1992 are 12.0%, 24.1%, and 36.1%, respectively.

Both pure technical and scale inefficiency are generally decreasing as farm size is increasing, even though those of 1-2ha and

2-3ha farms show no difference, which might happen because of the similiarity in the farming technologies used and in the institutional barriers confronted by farms. Thus, we can draw a conclusion that the hypothesis is not rejected, implying that production efficiency can be enhanced via the enlargement of farm size. Furthermore, the result that the average scale inefficiency of farm households above 3ha is 21.3%, suggests that institutional arrangement is necessary in order to support the enlargement of farm size. Only with the enlargement of acreage without efforts to diffuse the appropriate technology and to eliminate the institutional barriers to promote the scale efficiency, however, we can expect to enhance the efficiency of rice production merely by 5~8 %.

Table 3. Estimated Results of Inefficiency in Rice Production of Sample Farms

Classification	Number of Farms (farm)	Average Farm Size (ha)	Pure Technical Inefficiency (%)	Scale Inefficiency (%)	Total Technical Inefficiency (%)
Total	1,203	0.98	12.0	24.1	36.1 (5.3)
less than 0.5ha	343	0.33	13.0	25.0	38.0 (6.1)
0.5 ~ 1.0	430	0.71	12.1	24.2	36.3 (4.9)
1.0 ~ 2.0	324	1.39	11.3	23.4	34.7 (4.6)
2.0 ~ 3.0	79	2.40	11.3	23.4	34.7 (6.8)
more than 3.0ha	27	3.94	9.2	21.3	30.5 (3.1)

Note : The number in ( ) is standard deviation.

V. Conclusions and Policy Implications

This paper aimed to measure the extent of technical inefficiency among a sample of Korean rice farms by farm size using a ray-homothetic stochastic production function and to test a hypothesis that efficiency of rice production can be enhanced through the enlargement of farm size.

Using 1,203 sample data randomly selected from PCAG to measure the production efficiency of rice farms, a ray-homothetic stochastic frontier production function was estimated. A scale function was derived by using the parameters of the estimated frontier production function and the intensity of input use.

The average pure technical, scale, and total technical inefficiencies of the whole rice production sample farms in 1992 were 12.0%, 24.1% and 36.1%, respectively. And both pure technical and scale inefficiencies were decreasing as farm sizes were increasing. This implies that the hypothesis, which production efficiency can be enhanced via the enlargement of farm size, is not rejected. Furthermore, the fact that the average scale inefficiency of farms above 3ha was 21.3%, implies that some institutional arrangements are still needed to support the enlargement of farm size.

Results of inefficiency measurement were calculated under the assumptions that the present production technology of leading farms could be diffused thoroughly to other farms and that the institutional barriers to hinder the perfect competition could be perfectly removed. But it is actually impossible to diffuse advanced technology to all farms and to remove institutional barriers entirely. If the government and farmers cooperate well, the frontier technology and the institutional barriers can be diffused and removed to the considerable extents. Furthermore, the technical inefficiencies in this analysis were measured assuming that the production technology of leading farms is the frontier technology available now. Therefore, the further reduction of rice production cost can be achieved if new advanced-technology is developed. Only with the enlargement of acreage without efforts to diffuse the appropriate technology and to eliminate the institutional barriers to promote the scale efficiency, however, we can not expect to enhance the efficiency of rice production so much.

The results of this study have several important policy implications. First, the potentials of efficiency enhancement in rice production should not be underestimated. Second, the government's structural policy focusing on the enlargement of farm size is desirable to improve the efficiency of rice production. However, it should be noted that it is more important to remove the institutional and technological barriers than only to pursue the enlargement of farm size. Finally, we should not overlook that the development of new production technology as well as the diffusion of current advanced technolgy plays an important role in improving the efficiency of rice production.

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