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TECHNOLOGICAL CHANGE, TECHNICAL AND ALLOCATIVE EFFICIENCY IN CHINESE AGRICULTURE: THE CASE OF RICE PRODUCTION IN JIANGSU

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ABSTRACT

This paper develops a frontier shadow cost function approach to estimate empirically the effects of technological change, technical and allocative efficiency improvement in Chinese agriculture during the reform period (1980-93). The results reveal that the first phase rural reforms (1979-84) which focused on the decentralization of the production system have had significant impact on technical efficiency but not allocative efficiency. During the second phase reforms which was supposed to focus on the liberalization of rural markets, technical efficiency improved very little and allocative efficiency has increased only slightly, however. In contrast, the rate of technological change continued to increase, although at a declining rate during the second phase reform.

CONTENTS

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1. INTRODUCTION

Institutional changes and market reforms initiated in 1979 have had great impacts on China's agricultural production and productivity growth. Numerous studies have examined the effects of these reforms (Lin 1992; Fan 1991; Wen 1993; McMillan et al. 1989), but all used the production function approach. Production functions are easy to estimate, and can be used to identify the effects on production growth of technological change derived from the use of new technologies and technical efficiency improvement due to institutional and market reforms. But the production function approach cannot measure the impact of improvement in allocative efficiency due to these changes and reforms. This has become an increasingly serious problem because allocative efficiency improvement may have been a more important component of overall efficiency improvement in Chinese agriculture since 1984. The government did not begin to focus on the reform of the rural input and output market system (the so-called second-phase

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reforms) until 1985.[1] It is anticipated that the second-phase reforms may have improved farmers' allocative efficiency significantly since 1985, but it is not known or to what extent farmers have improved their allocative efficiency, in addition to their improvement in technology and technical efficiency. The objective of this study is to fill this gap in our knowledge.

This study differs from the previous studies in several aspects. First, the study empirically estimates a stochastic frontier shadow cost function for Chinese agriculture using a flexible functional form. One of the problems in estimating the cost function for a centrally planned economy such as China is government distortion in both input and output markets. By using this new approach, the effects of these government distortions on allocative efficiency can be estimated. Second, technological change and technical and allocative efficiency improvement are estimated simultaneously from the same cost function. Traditionally, technological change and technical efficiency are estimated based on the assumption of allocative efficiency, but this assumption may not be realistic, and may result in biased estimates. Third, the study covers a longer period (1980-93), making it possible to identify the effects of different phases of the reforms on efficiency improvement.

The paper is organized as follows: In the next section, a framework to measure both technical and allocative efficiency plus technological change is developed, using the cost function framework. Section 3 describes the model specification, while Section 4 describes the data and estimation procedures. In Section 5, estimated results and

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[1]For more information on input and out market reforms, see Lin 1989 and 1991.

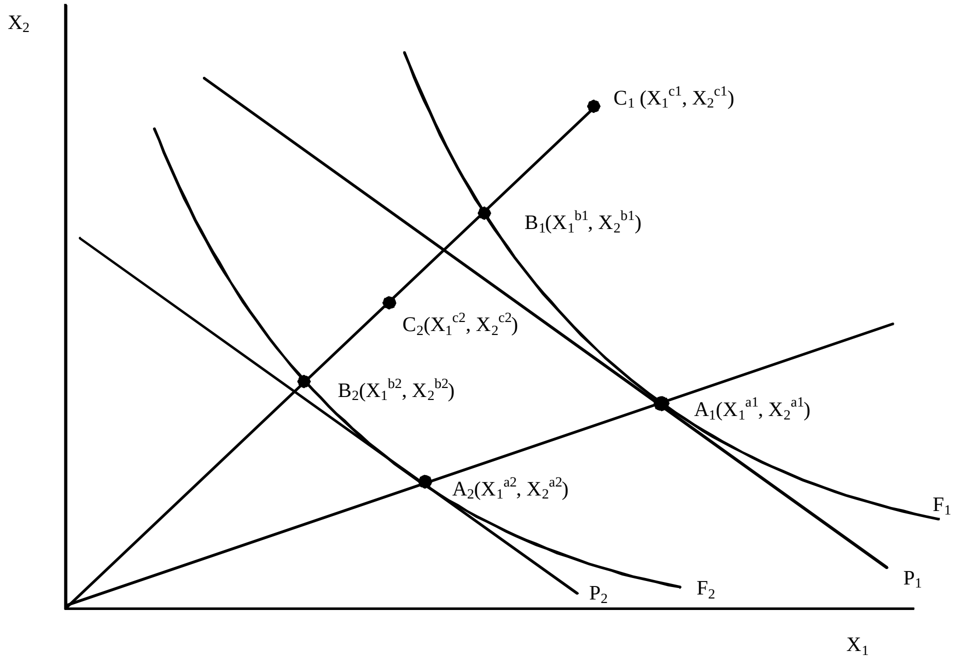
measures of technological change and efficiency improvement are presented. Conclusions are drawn in the final section.

2. CONCEPTUAL FRAMEWORK

Technological change and efficiency improvement are important sources of production growth in any economy. *Technological change* is defined as a shift in the frontier production function. Efficiency improvement can be further decomposed into technical and allocative efficiency. The concept of technical efficiency is based on input and output relationships. *Technical inefficiency* arises when actual or observed output from a given input mix is less than the maximum possible. *Allocative inefficiency* arises when the input mix is not consistent with cost minimization. Allocative inefficiency occurs when farmers do not equalize marginal returns with true factor market prices.

Different concepts of efficiency and technological change can be illustrated using Figure 1, with two inputs, X_1 and X_2, and a single product, Y. The two isoquants F_1 and F_2 represent production frontiers for the same physical output at time 1 and time 2, respectively. They are the best practice technologies used by farmers. However, a producer may not reach the frontier because of technical inefficiency. Points A_1, B_1, A_2 and B_2 are technically efficient, but C_1 and C_2 are not. The price of input X_1 relative to X_2 is represented by P_1 and P_2 for the two time periods, respectively. Allocative efficiency occurs if the inputs are combined so that their marginal products are in the same ratios as

Figure 1 Effects of technological change, and efficiency improvement on production



their relative prices. Points A_1 and A_2 are allocatively efficient, but B_1 and B_2 are not. A_1 and A_2 are both technically and allocatively efficient because they are on the production frontiers and are located where the ratios of marginal products are the same as the ratios of relative prices.

In the cost function framework, technological change can be measured as $-[C(X_1^{a2}, X_2^{a2})-C(X_1^{a1}, X_2^{a1}]/C(X_1^{a1}, X_2^{a1})$; technical efficiency can be measured as $C(X_1^{b1}, X_2^{b1})/C(X_1^{c1}, X_2^{c1})$ at time 1, and $C(X_1^{b2}, X_2^{b2})/C(X_1^{c2}, X_2^{c2})$ at time 2, respectively; and allocative efficiency can be measured as $C(X_1^{a1}, X_2^{a1})/C(X_1^{b1}, X_2^{b1})$ at time 1, and $C(X_1^{a2}, X_2^{a2})/C(X_1^{b2}, X_2^{b2})$ at time 2, respectively. Economic efficiency is the product of technical efficiency and allocative efficiency. Therefore, economic efficiency is $C(X_1^{a1}, X_2^{a1})/C(X_1^{c1}, X_2^{c1})$ at time 1, and $C(X_1^{a2}, X_2^{a2}/C(X_1^{c2}, X_2^{c2})$ at time 2, respectively. The model specified in the next section is based on this conceptual framework.

3. MODEL SPECIFICATION

Economic theory argues that reducing government control of factor markets is an efficient policy because the free market best determines prices according to the relative scarcity of resources. Fan (1991) developed a frontier production function approach to measure both technological change and technical efficiency improvement in China's agricultural production growth from 1965 to 1985. However, the production function approach cannot model the effect of allocative efficiency improvement on production growth. Wang et al. (1996) developed a frontier shadow profit function to study both technical and allocative efficiency using cross-sectional household survey data. But changes of efficiency and technology over time were impossible to model due to unavailability of panel data. Furthermore, different functions are used in estimating technical and allocative efficiency in Wang et al.'s study. In this paper, a stochastic frontier shadow cost function approach is developed and applied to Chinese agriculture to measure three different effects on production: technological change, technical and allocative efficiency improvement.

It is presumed that farmers minimize cost subject to their technology and government policy constraints. Due to government regulations and input supply shortages, there exist shadow prices for inputs. Farmers make their decisions on shadow prices of factor inputs in order to minimize shadow costs. In a free-market situation, the shadow price is equal to the market price. This condition, however, does not hold in Chinese agriculture because of government distortions of factor markets, such as price controls, rationing of certain inputs, and control of labor migration. As the government gradually eliminates controls in input markets, the difference between the shadow price and the observed price should diminish, and farmers' allocative efficiency should improve as a result. To model farmers' decision making, assume that the decision makers minimize a well-defined but unobserved shadow cost function subject to unobserved shadow input prices:

$$C^s = C^s(Y, P^s), \tag{1}$$

where Y is output, and P_s is a vector of shadow input prices. If the farmer is efficient in choosing the cost-minimizing levels of the inputs, then

$$\frac{\partial f(X)/\partial X_i}{\partial f(X)/\partial X_j} = \frac{P_i^s}{P_j^s} \tag{2}$$

where $f(X)$ is neoclassical production function common to all firms. We define ξ_i as the ratio of the shadow price to the observed price for input i,

$$\xi_i = \frac{P_i^s}{P_i} \tag{3}$$

If there exists a well-developed input market without government distortions, then $\xi_i = 1$. But if ξ_i differs from 1, then factor input markets are distorted by policies, causing inefficient use of resources.

Allocative efficiency can be measured from a shadow profit or a shadow cost function. The shadow profit function framework was developed by Lau and Yotopoulous (1971), and then extended by Atkinson and Halvorsen (1980), and Lovell and Sickles (1983). The shadow cost function approach was first introduced by Toda (1976) and later applied by Atkinson and Halvorsen (1984). Recently, some economists have used the shadow cost function approach to measure both technical and allocative efficiency. Atkinson and Cornwell (1994) developed a shadow cost function approach to identify both technical efficiency and allocative efficiency of the major U.S. airlines. Parker (1995) used the similar approach in his study on China's construction industry. But the cost functions they estimated are deterministic.[2] One of the primary criticisms of the deterministic estimators is that no account is taken of the possible influence of measurement errors and other noise upon the shape and positioning of the estimated frontier, since all observed deviations from the estimated frontier are assumed to be the results of technical inefficiency (Coelli 1995; Bauer 1990).

To avoid this problem, a stochastic frontier shadow cost function approach is developed and used in this study. It is assumed that decision makers minimize a well-defined but unobserved shadow cost function subject to unobserved shadow input prices. Instead of all inputs, we assume that fertilizer, machinery, labor, and pesticides are variable.[3] The shadow cost function C^S is assumed to be a function of shadow prices

[2]Atkinson and Cornwell (1994) normalize efficiency measure to 1 for the most efficient firm.

[3]The cost function is estimated on a per *mu* basis, assuming constant return to scale. One mu is equal to 1/15 hectare.

P_i^s (i=1, 2, 3, and 4), and is specified as the translog functional form which provides a convenient second-order approximation to any arbitrary continuously twice-differentiable cost function,

$$lnC^S = A_0 + \alpha_t T + \tfrac{1}{2}\alpha_{tt} T^2 + \alpha_y lnY + \tfrac{1}{2}\alpha_{yy} lnY lnY + \alpha_{yt} T \times lnY + \sum_{i=1}^{4} \alpha_i lnP_i^s + \sum \alpha_{iy} lnY lnP_i^s + \tfrac{1}{2}\sum\sum \alpha_{ij} lnP_i^s lnP_j^s + \sum \alpha_{it} T \times lnP_i^s + e, \tag{4}$$

where A_0 is a set of regional specific dummies; and T is time trend. The disturbance term, $e=V+U$, is assumed to be consistent with the frontier concept. We assume V to be normally distributed to reflect the random factors such as weather, and use a one-sided disturbance U to represent the *technical* inefficiency component[4], i.e., V is normal with mean zero and variance σ_v^2, $|u|$ is truncated normal with variance σ_u^2, and $E(u_{it}v_{it}) = 0$.

Since cost functions must be linearly homogenous and concave in factor prices, the following restrictions are imposed:

$$\sum_{i=1}^{4} \alpha_i = 1; \quad \sum_{i=1}^{4} \alpha_{ij} = 0 \;\forall j$$
$$\sum_{i=1}^{4} \alpha_{it} = 0; \quad \sum_{i=1}^{4} \alpha_{iy} = 0. \tag{5}$$

Symmetry is also imposed on the α_{ij} parameters. By Shephard's Lemma, the shadow share of the i^{th} input is the first partial derivative of lnC^S with respect to lnP_i^s,

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[4]Note that only the technical inefficiency component rather than overall cost inefficiency is captured in this term, because the shadow cost function is estimated as the one for the most allocatively efficient firm.

$$S_i^s = \frac{\partial \ln C^s}{\partial \ln P_i^s} = \alpha_i + \sum_{j=1}^{4} \alpha_{ij} \ln P_j^s + \alpha_{iy} \ln Y + \alpha_{it} T + \varepsilon_i. \qquad \textbf{(6)}$$

The error terms ε_i in the shadow share equation represent statistical noises, such that $E(\varepsilon_i) = 0$, and $E(\varepsilon_i \varepsilon_j) = \sigma_{ij}\mathbf{I}$. It is also assumed that e and ε_i are independent of each other.

The shadow cost function in equation (4) cannot be directly estimated, however, since neither shadow prices nor shadow costs are directly observed. Instead, input prices, P_i, are observed, and it is assumed that, the ratio of shadow price to observed price, ξ_i, is an estimable function of other variables. We assume ξ_i is a function of land-to-labor ratio (ALR), and the ratio of government procurement prices to market prices of rice output (GMR). The land-to-labor ratio variable captures the effect on efficiency of relaxation of migration control policy and labor movement due to the rapid development of rural industry during the reform period, while the ratio of government to market prices capture the effect of changes in government price policies. A regional dummy PD (= 1 for southern prefectures of Jiangsu, and 0 for northern prefectures) is also added to capture the regional difference in shadow prices[5].

$$\ln \xi_i = \xi_{i0} + \xi_{i1} \ln ALR + \xi_{i2} \ln GMR + \xi_{i3} PD. \qquad \textbf{(7)}$$

[5]Due to linear homogeneity in prices, only relative price inefficiency can be estimated; therefore, ξ_f (fertilizer) is arbitrarily set to unity, and ξ_l (labor), ξ_p (pesticide), and ξ_m (machinery) are relative shadow price ratios.

From equations (4) and (6), the observed cost function *C* can be derived as a function of the shadow (minimum) cost function and the shadow shares[6], such that

$$\ln C = \ln C^s + \ln\left(\sum_{i=1}^{4} \frac{S_i^s}{\xi_i}\right) + e, \tag{8}$$

and the resulting observed share equations S_i are:

$$S_i = \frac{\partial \ln C}{\partial \ln P_i} = \frac{S_i^s}{\xi_i}\left(\sum_{j=1}^{4} \frac{S_j^s}{\xi_j}\right)^{-1} + \varepsilon_i. \tag{9}$$

Equations (8) and (9) can be estimated if the error terms of these two equations are assumed to be seemingly unrelated.[7] Because the four observed shares sum to unity by definition, the last share equation S_f is dropped. The results are invariant to the share equation dropped.

Efficiency indexes and the rate of technological change can be calculated from the estimated stochastic frontier shadow cost function. Allocative efficiency, the ratio of shadow cost to actual cost, is measured as:

$$\eta^A = \frac{C^s}{C} \tag{10}$$

[6]For derivation of equations (8) and (9), see Atkinson and Cornwell (1994), among others.

[7]Wang et al. (1996) and Parker (1995) have also proved that equations (8) and (9) can be estimated.

This index is unity if $\xi_i = 1$, œ*i*.

Based on the conditional distribution of *U*, given the distribution of *V*+*U*, the technical efficiency can be measured as[8]:

$$\eta^T = 1 - E(U|e) = 1 - \frac{\sigma_U \sigma_V}{\sigma}\left[\frac{f(e\lambda/\sigma)}{1 - F(e\lambda/\sigma)} - \frac{e\lambda}{\sigma}\right], \tag{11}$$

where $\lambda = \sigma_U/\sigma_V$ and $\sigma_2{}^2 = \sigma_U{}^2 + \sigma_V{}^2$, and f and F are the standard normal density function and the standard normal distribution function, respectively evaluated at $(e\lambda/\sigma)$.

Overall economic efficiency is the product of both technical and allocative efficiency.

$$\eta = \eta^A \eta^T. \tag{12}$$

Using the estimated stochastic frontier shadow cost function, the rate of technological change can be derived as:

$$-\frac{\partial lnC^s}{\partial t} = -(\alpha_t + \alpha_{tt} * T + \sum_{i=\cap}^{\infty} \alpha_{it} lnP_i^s + \alpha_{yt} lnY). \tag{13}$$

[8]For detailed derivation of (12), see Jondrow et al.; Ali et al. (1996) also used this measure in a cost function framework.

4. DATA DESCRIPTION AND ESTIMATION PROCEDURES

Time-series cross-prefecture data are used in this study. They come from the *Cost and Production Survey* conducted by the Jiangsu Provincial Price Bureau. Jiangsu Province is one of the most developed areas in terms of both agriculture and nonagriculture. The survey covers most of the major crops in the province and in 1993 more than 900 households were surveyed. The well-trained survey team members at the village, township, county, prefectural, and provincial levels recorded quantities and costs of major inputs, and production for each commodity periodically every year. Only rice is chosen for the purpose of this study because of its significance and representativeness in the province's agricultural production. For this analysis, aggregated cell means of the prefectural households were used rather than individual household observations. Fourteen years, 1980 to 1993, and 11 prefectures (Nanjing, Wuxi, Suzhou, Changzhou, Xuzhou, Lianyungang, Huaiyin, Yianchang, Nanton, Yangzhou, and Zhengjiang) were included (a total of 154 observations). Input prices were taken from the *China s Price Yearbooks* and Jiangsu Provincial Price Bureau.

Since the final objective is to estimate the stochastic frontier shadow cost function (equation 4), an iteration procedure is used in the estimation[9]:

1. Both equations (8) and (9) are estimated as a system using the nonlinear seemingly unrelated regression technique (SURE). The error terms in these

[9]Ideally, we can estimate equations (8) and (9) with (8) specified as a stochastic frontier function and (9) as seemly unrelated. But there are not econometric packages available for estimating a frontier function in a system.

equations are assumed to be seemingly unrelated with e assumed as traditional normal distribution with zero mean and variance of σ_e^2.

2. The second step involves the estimation of equation (4) assuming the error terms consistent with the frontier framework. Both predicted shadow costs and prices are used as dependent and independent variables. The predicted value of lnC^s is calculated from equation (8) using estimated ξ_is from step 1. Similarly, the predicted value of P_i^s is calculated from equation (3).
3. Using estimated parameters αs from equation (4), the share equations (9) are re-estimated in order to obtain new estimates of ξ_is
4. Using newly estimated ξ_is from step 3, the equation (4) is re-estimated and this process is reiterated until the αs converge.

5. RESULTS

The estimated coefficients of the convergent cost function for Jiangsu rice production are presented in Table 1. Most of the estimates are statistically significant at the 5 percent significance level. The Wald test rejected that $\xi_i = 1$ for labor, machinery and pesticide inputs at the one percent significance level, indicating that the shadow prices of these inputs are significantly different from their observed prices. The value of

Table 1 Estimates of stochastic frontier shadow cost function

Parameter	Coefficient	t-ratio	Parameter	Coefficient	t-ratio
α_t	-0.0353	1.989*	ξ_{l0}	-0.8355	-2.873
α_{tt}	-0.0018	-0.483	ξ_{l1}	0.4451	4.096*
α_y	-0.6163	-1.889*	ξ_{l2}	-0.0233	-0.308
α_{yy}	0.3571	0.345	ξ_{l3}	-0.3431	-3.285*
α_{yt}	0.0334	1.066	ξ_{m0}	1.3686	4.448*
α_l	0.3324	6.841*	ξ_{m1}	-0.3938	-3.416*
α_m	0.0672	2.894*	ξ_{m2}	-0.1982	-3.581
α_p	0.1169	2.824*	ξ_{m3}	-1.9990	-5.116*
α_{yl}	0.0451	1.894*	ξ_{p0}	-1.6672	-2.823*
α_{ym}	-0.0253	-1.315	ξ_{p1}	-0.3031	-2.481*
α_{yp}	0.0032	0.487	ξ_{p2}	-0.1759	-2.362*
α_{tl}	-0.0041	-1.723	ξ_{p3}	1.8990	5.599*
α_{tm}	0.0047	3.508*	λ	1.7721	6.226*
α_{tp}	-0.0014	-1.805*	σ^2_U	0.0201	2.967*
α_{ll}	0.0135	1.876*	σ^2_V	0.0042	8.401*
α_{lm}	-0.0108	-2.343*			
α_{lp}	0.0021	0.917			
α_{mm}	0.0616	3.751*			
α_{mp}	-0.0483	-3.567*			
α_{pp}	0.0173	1.736			

Notes: The subscripts l, m, p, t, and y stand for labor, machinery, pesticide, the time trend, and output. Asterisk indicates significant at the 5% level. Regional dummies are not reported.

λ is 1.772, which implies that the one sided error term U dominates the symmetric error V.

In Table 2, mean statistics of the estimated stochastic frontier shadow cost function are shown for two periods, 1980-84 and 1985-93, and for the whole period, 1980-93. These statistics are calculated for each observation and reported at their mean. These statistics include estimated shadow factor price ratios, and observed cost shares as well as estimated shadow shares. The changes in the ratios of shadow prices to observed prices indicate that the observed price ratios of labor, machinery and pesticides have moved closer towards unity (although only marginally). Comparing the shadow and actual cost shares of inputs reveals that farmers overused the labor input by more than 87 percent during the first phase reforms. Even during the second phase reforms from 1985 to 1993, the actual labor cost share was still more than 68 percent higher than the shadow cost share. This confirms that there still exists a large surplus of labor in rural China. The shadow cost share of fertilizer was more than 60 percent of the observed fertilizer share, implying that farmers have underused fertilizer relative to labor. The discrepancy between the shadow and actual shares of pesticide and machinery has been very small, however.

Measures of technical and allocative efficiency, and the rate of technological change are presented in Table 3. Technical efficiency was relatively low at the beginning of the reforms. But as reforms progressed, it improved significantly, by 8.5 percent per year from 1980 to 1984. But after 1985, technical efficiency improved very little. These results confirmed many speculations that the effect of the household production responsibility system had been largely exhausted after 1985. During the first phase of reforms, allocative efficiency improved very little. Even during the second phase of reforms, it increased only slightly. Therefore, we cannot confirm many scholars' belief

Table 2 Mean statistics of the stochastic frontier shadow cost function estimation

	1980 - 84	1985 - 93	1980 - 93
ξ_f	1.00	1.00	1.00
ξ_m	2.11	2.02	2.06
ξ_p	0.62	0.63	0.63
ξ_l	0.39	0.41	0.40
S_f	0.31	0.32	0.32
S_f^s	0.48	0.54	0.52
S_m	0.04	0.06	0.05
S_m^s	0.13	0.08	0.10
S_p	0.06	0.07	0.07
S_p^s	0.08	0.09	0.08
S_l	0.59	0.49	0.52
S_l^s	0.31	0.29	0.30

Notes: S_f, S_m, S_p, and S_l are actual factor shares of fertilizer, machinery, pesticides, and labor, while S_f^s, S_m^s, S_p^s, and S_l^s are shadow factor shares for these inputs.

Table 3 Measures of efficiency improvement and technological change

Year	Allocative efficiency	Technical efficiency	Economic efficiency	Technological change rate
1980	0.688	0.611	0.420	0.026
1981	0.689	0.612	0.421	0.032
1982	0.700	0.696	0.488	0.037
1983	0.700	0.796	0.557	0.040
1984	0.704	0.848	0.597	0.043
1985	0.695	0.819	0.568	0.043
1986	0.715	0.852	0.609	0.045
1987	0.719	0.839	0.603	0.046
1988	0.707	0.839	0.593	0.047
1989	0.702	0.878	0.616	0.051
1990	0.701	0.864	0.606	0.054
1991	0.731	0.859	0.628	0.058
1992	0.725	0.854	0.619	0.059
1993	0.745	0.909	0.677	0.062
Annual growth rate (%)				
1980-84	0.593	8.533	9.177	13.275
1985-93	0.779	1.170	1.958	4.235
1980-93	0.614	3.102	3.734	6.980

that the second phase of reforms have improved allocative efficiency substantially.[10] This may indicate that the input market in Jiangsu agriculture is still distorted by government policies, despite the efforts that the government has made to liberalize the market. Economic efficiency, the combined effects of both technical and allocative efficiency, improved sharply from 1980 to 1984, but began to stagnate after 1984, due to the lack of improvement in both technical and allocative efficiency.

The rate of technological change accelerated during the first phase reform, with an annual growth of 13.3 percent per annum. This is a result of long-term investment in agricultural research, irrigation, and other technologies in Jiangsu agriculture. In fact, the province has one of the most productive research systems among all provinces. More than 80 percent of total crop areas are sown with high-yielding varieties developed by the provincial as well as prefectural research institutes. The rate of technological change continued to increase during the second phase reforms, although at a slower rate.

Allocative efficiency varies greatly among regions (Table 4). The northern part of the province (Xuzhou, Nanton, Yangcheng and Huaiyin) has higher allocative efficiency. The lower allocative efficiency in southern Jiangsu may be due to heavy subsidies from rural industry to rice production there, these subsidies may have severed misallocation of inputs. The higher allocative efficiency in the relatively poor North also confirms T.W. Schultz's hypothesis that small farmers are efficient in allocating their resources although

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[10]The fact that this study only analyzes the allocative efficiency among inputs, but not among outputs may underestimate the improvement in allocative efficiency. Furthermore, this study only covers one province in China, and the conclusion may not be generalized for the whole country.

Table 4 Regional differences in efficiency levels

	Allocative efficiency	Technical efficiency	Economic efficiency
Nanjing	0.64	0.78	0.49
Wuxi	0.65	0.80	0.52
Xuzhou	0.78	0.80	0.63
Changzhou	0.64	0.84	0.54
Suzhou	0.68	0.78	0.53
Nanton	0.80	0.76	0.61
Lianyungang	0.72	0.85	0.61
Huaiyin	0.76	0.78	0.59
Yancheng	0.78	0.78	0.61
Yangzhou	0.69	0.79	0.54
Zhengjiang	0.66	0.84	0.55
Average	0.71	0.80	0.57

they are poor. In contrast to allocative efficiency, technical efficiency has relatively small regional variations, ranging from 0.76 in Nanton to 0.85 in Lianggungang. Therefore, it is not surprising that the variation in economic efficiency largely comes from differences in allocative efficiency.

6. CONCLUSIONS

Rural reforms since 1979 have been very successful, according to a number of recent studies. But they all failed to measure the changes in allocative efficiency due to these reforms. This study applied a stochastic frontier shadow cost function approach to estimate the improvement of both technical and allocative efficiency. The analysis confirms the findings of previous studies about the importance of the growth-promoting effects of efficiency improvements resulting from the rural reforms. More importantly, the importance of these efficiency improvements varied markedly over time and across regions. Technical efficiency improved substantially in the early stage of the reforms, while improvement of both technical and allocative efficiency stagnated during the second phase of reforms. Overall economic efficiency has improved substantially, but the rate has declined since 1984. The rate of technological change continued to increase over the whole study period. This is a result of long-term government investment in technology and rural infrastructure (Fan and Pardey 1997).

These results have important policy implications for the government in seeking to increase further production and productivity growth. The large regional variation in allocative efficiency among regions implies that China still has great potential to promote production growth by reducing regional differences in allocative efficiency. The stagnation in technical efficiency after 1984 may be a result of deterioration of the extension service after the reforms. If so, then the extension system also may need to be strengthened in order to gain further efficiency in production.

As both technical and allocative efficiency have reached a plateau (0.75 for allocative efficiency and 0.91 for technical efficiency), technological change will be the main source of production growth in the future. This implies that the government should continue to increase its support for public investment in infrastructure and technology such as roads, irrigation, and research and extension.

REFERENCES

Ali, F., Parihk, A., and M. Shah. 1996. Measurement of economic efficiency using the behavioral and stochastic cost frontier approach. *Journal of Policy Modeling* 18: 271-87.

Atkinson, S. and C. Cornwell. 1994. Parametric estimation of technical and allocative inefficiency with panel data. *International Economic Review* 35: 231-243.

Atkinson, S. and R. Halvorsen. 1980. A test of relative and absolute price efficiency in regulated utilities. *Review of Economics and Statistics* 62: 81-88.

Atkinson, S. and R. Halvorsen. 1984. Parametric efficiency tests, economies of scale, and input demand in U.S. electric power generation. *International Economics Review* 25: 647-662.

Bauer, P.W. 1990. Recent developments in the econometric estimation of frontiers. *Journal of Econometrics* 46: 39-56.

Coelli, T.J. 1995. Recent developments in frontier modelling and efficiency measurement. *Australia Journal of Agricultural Economics* 39: 219-45.

Editorial Committee of China's Agricultural Yearbooks (1980-94). *China s Agricultural Yearbook* (various issues). Beijing: China's Agricultural Press (in Chinese).

Fan, S. and P. Pardey. 1997. Research, productivity, and output growth in Chinese agriculture. *Journal of Development Economics* 53: 115-137.

Fan, S. and V. Ruttan. 1992. Technical change in centrally planned economies. *Agricultural Economics* 6: 301-314.

Fan, S. 1991. Effects of technological change and institutional reform on production growth in Chinese agriculture. *American Journal of Agricultural Economics* 73: 266-275.

Farrell, M.J. 1957. The measurement of productive efficiency. *Journal of Royal Statistics Society,* Ser. A. 120: 253-281.

Jondrow, J., C. Lovell, I.S. Materov, and P. Schmidt. 1982. On estimation of technical inefficiency in the stochastic frontier production function model. *Journal of Econometrics* 19: 233-38.

Lau, L. J. and P.A. Yotopoulos. 1971. A test for relative efficiency and an application to Indian agriculture. *American Economic Review* 61: 94-109.

Lin, J. 1989. Rural factor markets in China after the household responsibility reform. *Chinese Economic Policy*, ed. Bruce Reynolds. New York: Wiley.

Lin, J. 1991. Prohibition of factor market exchanges and technological choice in Chinese agriculture. *The journal of development studies* 27: 1-15.

Lin, J. 1992. Rural reforms and agricultural growth in China. *American Economic Review* 82: 34-51.

Lovell, C.A.K. and R. Sickles. 1983. Testing efficiency hypotheses in joint production: A parametric approach. *Review of Statistics and Economics* 65: 51-58.

McMillan, J., J. Whalley, and L. Zhu. 1989. The impact of China's economic reforms on agricultural productivity growth. *Journal of Political Economy* 97: 781-807.

Parker, E. 1995. Shadow factor price convergence and the response of Chinese state-owned construction enterprises to reform. *Journal of Comparative Economics* 21: 54-81.

Toda, Y. 1976. Estimation of a cost function when the cost is not minimum: The case of Soviet manufacturing industries, 1958-71. *Review of Economics and Statistics* 58: 259-268.

Wang, J., E. Wailes, and G. Cramer. 1996. A shadow-price frontier measurement of profit efficiency in Chinese agriculture. *American Journal of Agricultural Economics* 78: 146-156.

Wen, G.J. 1993. Total factor productivity change in China's farming sector: 1952-1989. *Economic Development and Cultural Change* 42: 1-41.