# A Decomposition of Total Factor Productivity Growth: The Case of Chinese Agricultural Growth Before and After Reforms

**K.P. Kalirajan, M.B. Obwona, and S. Zhao**

Our objective in this paper is to explain a method to decompose the sources of total factor productivity (TFP) growth into technological progress and changes in technical efficiency within the framework of the varying coefficients frontier production function. An empirical application is demonstrated using the Chinese provincial-level agricultural data covering the period 1970–87. The results indicate that TFP growth in the prereform period was negative in twenty out of twenty-eight provinces and that it was positive in almost all provinces during the reform periods, while negative in sixteen out of twenty-eight provinces in the postreform periods of 1984–87.

*Key words*: Chinese agriculture, technical efficiency, technological progress, total factor productivity growth, varying coefficients frontier production function.

Output growth overtime is usually attributed to growth in inputs and/or improvement in total factor productivity. While measuring the sources of output growth, the contribution of total factor productivity is always estimated as a residual, after accounting for the growth of inputs. Quite often, the contribution of total factor productivity is interpreted as the contribution of technical progress. Such an interpretation implies that improvement in productivity arises from technical progress only. This assumption is valid only if firms (farmers) operate on their production frontiers producing the maximum possible output or realizing the full potential of the technology. Operation on the frontier can be achieved if firms (farmers) follow the best practice methods of application of the technology commonly referred to as "technical efficiency" in the literature. So far as firms (farmers) do not operate on their frontiers due to various nonprice and organizational factors, but somewhere below the frontiers, technical progress cannot be the only source of total factor productivity growth. A substantial increase in total factor productivity under these circumstances still can be realized by improving the method of application of the given technology.

Thus, the decomposition of total factor productivity growth into technological progress and changes in technical efficiency provide more information on the status of the production technology applied by firms. For example, the decomposition analysis facilitates examining whether technological progress is stagnant over time and whether the given technology has been used in such a way as to realize its potential fully. From the policy point of view, these questions are important because without using the existing technology to its full potential, embarking on introducing new technologies is not meaningful.

Using the Chinese agricultural provincial-level panel data and the stochastic frontier production function approach, Fan estimated the total factor productivity growth as the sum of technical progress and technical efficiency improvement. These components of total factor productivity growth were obtained by taking

K.P. Kalirajan is with the Division of Economics, Research School of Pacific and Asian Studies, The Australian National University; M.B. Obwona is with the Economic Policy Research Centre, Uganda; and S. Zhao is with the Bureau of Transport and Communications Economics, Canberra, Australia.

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the total derivatives of the stochastic production frontier function with respect to time. However, in accounting for the sources of total output growth, Fan treated technological change as the residual. Moreover, the specifications of the frontier production function followed in Fan's study implicitly assume the following: (*i*) in a given period, the production frontier is neutrally shifted from the "average" and the realized production functions; (*ii*) over time the production frontiers themselves shift neutrally, implying that the technical change is also of a neutral type; and (*iii*) the rate of technical change over time is constant among firms. These assumptions are restrictive. Without detracting from the important contribution made by Fan, this study suggests an alternative methodology of decomposing TFP growth to eliminate the above restrictive assumptions.

By following the varying coefficients production frontier approach developed in Kalirajan and Obwona, these restrictive assumptions can be eliminated. For example, in the varying coefficients approach, the production frontiers themselves shift nonneutrally over time. Thus, the technical change is of a nonneutral type. Secondly, while accounting for output growth in both the Solow "residual" and the above conventional TFP components approaches, technical change, which is one of the components of TFP growth, is not estimated but obtained as the "residual." In contrast, the procedure adopted in this paper estimates technical change as a shift in the frontiers and treats the total input growth as the residual, while accounting for the output growth.[1] The main advantage of not computing the input growth component but obtaining it as a residual is that problems usually encountered in productivity analyses, such as omission of some important inputs and adjustment for input quality changes, can be avoided.

## Varying Coefficients Production Frontier Approach

The distinction between technological progress and technical efficiency offers an important added dimension to the policy relevance of total factor productivity studies. For a given technology, it may be interesting to know whether the gap between "best practice" techniques and realized production methods is diminishing or widening over time. Changes in technical efficiency can be substantial and may outweigh gains from technical progress itself.[2] It is, therefore, important to know how far one is off the production frontier at any point in time, and how quickly one can reach the frontier. For instance, in the case of developing economies which borrow technology extensively from abroad, failures to acquire and adapt new technology will be reflected in the lack of shifts in the frontier over time.[3] The movement of the frontier over time reflects the success of explicit policies to facilitate the acquisition of foreign technology. Similarly, changes in technical efficiency over time and across individual firms will indicate the level of success of a number of important dimensions of industrial or agricultural policies.

In the growth-accounting exercise, when technical efficiency is measured using the conventional stochastic frontier production function approach of Aigner, Lovell, and Schmidt, of Meeusen and van den Broeck, and of Kalirajan and Flinn, the underlying assumption is that the frontier is a neutral shift from the realized production function. This constant-slope, variable-intercept approach raises a basic question about the concept of technical efficiency. Where does technical efficiency come from? How does a firm achieve its technical efficiency? The literature indicates that a firm obtains its full technical efficiency by following the best practice techniques, given the technology. In other words, technical efficiency is determined by the method of application of inputs, regardless of the levels of inputs (that is, scale of operation). This implies that different methods of applying various inputs will influ-

[1] Defining technical progress as the shift in the "best practice" techniques production frontier over time, Nishimizu and Page established its rate by direct estimation by programming techniques of a deterministic translog production frontier. Earlier applications of the production frontier in the study of technical changes include, for example, Forsund and Hjalmarsson, and Greene. Recently, the Nishimizu-Page approach has been generalized and applied, for example, to OECD financial services data by Fecher and Pestieau. Bauer illustrated the parametric approach to the decomposition of productivity growth into technical change and efficiency change using a dual translog stochastic cost frontier and data from the U.S. airline industry.

[2] For example, Fan found that 26.6% of total output growth in Chinese agriculture from 1965 to 1985 could be attributed to technical efficiency improvement and 15.7% to technical change.

[3] Nishimizu and Page indicate that in half of the former Yugoslavia's social sector industries there was no perceptible movement of the frontier during the period 1965–78.

ence the output differently. That is, the slope coefficients will vary from firm to firm. Therefore, the constant-slope approach of measuring technical efficiency is not consistent with the definition of technical efficiency. The following specification of the production process, which is consistent with the concept of technical efficiency, facilitates estimation of firm-specific technical efficiency for individual observations.

Assuming a Cobb-Douglas technology,

$$(1) \quad \ln Y_{it} = \alpha_{1i} + \sum_{j=2}^{T} \gamma_{jt} D_{jit} + \sum_{k=2}^{K} \alpha_{ki} \ln X_{kit}$$

$$i = 1, \ldots, N \qquad t = 1, \ldots, T$$

where $\alpha_{1i} = \bar{\alpha}_1 + u_{1i}$; if $j = t$ and zero otherwise; and $Y_{it}$ is the output level of the $i$th firm in period $t$; $X_{kit}$ is the level of the $k$th input used by the $i$th firm in period $t$; $\alpha_{1i}$ is the intercept term for the $i$th firm; $\alpha_{ki}$ is the actual response of the output to the method of application of the $k$th input by the $i$th firm; and $u_{ki}$ refers to the random variable term which has mean zero and variance $\sigma_{ukk}$. Let $\alpha_{ki} = \bar{\alpha}_k + u_{ki}$; $k = 1, 2, \ldots K$ and $i = 1, 2, \ldots N$ where $E(\alpha_{ki}) = \bar{\alpha}_k$, $E(u_{ki}) = 0$ and $\mathrm{var}(u_{ki}) = \sigma_{ujk}$ for $j = k$ and 0 otherwise.[4]

With these assumptions, model (1) can be written as

$$(2) \quad \ln Y_{it} = \bar{\alpha}_1 + \qquad \ln X_{kit} + w_{ki}$$

where

$$w_{ki} = \sum_{k=2}^{K} u_{ki} \ln X_{kit} + u_{1i}$$

$$E(w_{ki}) = 0 \text{ for all } i \text{ and } k;$$

$$\mathrm{var}(w_{ki}) = \sigma_{u11} + \sum_{k=2}^{K} \sigma_{ukk} \ln^2 X_{kit}$$

$$\mathrm{cov}(w_{ki}, w_{ji}) = 0 \text{ for } k \neq j.$$

Following the estimation procedures suggested by Hildreth and Houck, the mean response coefficients and the variances $\sigma_{ukk}$ can be estimated and the individual response coefficients $\alpha_{ki}$ can be obtained as described in Griffiths.

The assumptions underlying model (2) are as follows:

1. Technical efficiency is achieved by adopting the best practice techniques which involve the efficient use of inputs. Technical efficiency stems from two sources: (*a*) the efficient use of each input which contributes individually to technical efficiency and can be measured by the magnitudes of the varying slope coefficients $\alpha_{ki}$; and (*b*) any other firm-specific intrinsic characteristics which are not explicitly included may produce a combined contribution over and above the individual contributions. This "lump sum" contribution, if any, can be measured by the varying intercept term.
2. The highest magnitude of each response coefficient and the intercept form the production coefficients of the potential frontier production function. Let $\alpha^*$ and $\gamma^*$ be the estimates of the coefficients of the frontier production function, that is, $\alpha_k^* = \max\{\alpha_{ki}\}$; $\gamma_j^* = \max\{\gamma_{ji}\}$; $k = 1, \ldots, K$; $i = 1, \ldots, N$ and $j = 2, \ldots, T$.

Now the potential frontier output for individual observations can be calculated as

$$(3) \quad \ln Y_{it}^* = \alpha_1^* + \sum_{j=2}^{T} \gamma_j^* D_{jit} + \sum_{k=2}^{K} \alpha_k^* \ln X_{kit}; \qquad i = 1, \ldots N$$

where $X_{kit}$ is the actual level of $k$th input used by the $i$th firm in period $t$. A measure of technical efficiency denoted by, say, $TE$, can be defined as

$$(4) \quad TE_{it} = \frac{Y_{it}}{\exp(\ln Y_t^*)}$$

where the numerator refers to the realized output and the denominator shows the potential frontier output calculated from equation (3).

## Decomposition of TFP Growth

Figure 1 illustrates the decomposition of total output growth into input growth, technical progress, and technical efficiency improvement. In periods 1 and 2, the firm faces production frontiers $F1$ and $F2$ respectively. If a given firm has been technically efficient, output would be $y1^*$ in period 1 and $y2^{*\prime\prime}$ in period 2. On the other hand, if the firm is technically inefficient and does not operate on its frontier, then the firm's realized output is $y1$ in period 1

[4] Note that similar specifications also apply to the γ's. Lass and Gempesaw used this approach to study the supply of off-farm labor in Pennsylvania.

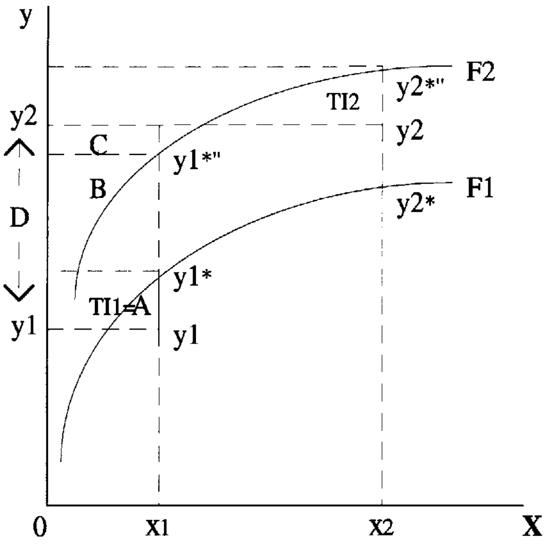


**Figure 1. Decomposition of output growth**

and $y2$ in period 2. Technical inefficiency ($TI$) is measured by the vertical distance between the frontier output and the realized output of a given firm, that is, $TI1$ in period 1 and $TI2$ in period 2, respectively. Hence, the change in technical efficiency over time is the difference between $TI1$ and $TI2$. Technological progress is measured by the distance between frontier $F2$ and frontier $F1$, that is, $(y2^{*''} - y2^*)$ using $x2$ input levels or $(y1^{*''} - y1^*)$ using $x1$ input levels. Denoting the contribution of input growth to output growth (between periods 1 and 2) as $\Delta y_x$, the total output growth, $(y2 - y1)$, can be decomposed into three components: input growth, technological progress, and technical efficiency change.

Referring to figure 1, the decomposition can be shown as follows:

$$
\begin{aligned}
(5)\quad D &= y2 - y1 \\
&= A + B + C \\
&= [y1^* - y1] + [y1^{*''} - y1^*] + [y2 - y1^{*''}] \\
&= [y1^* - y1] + [y1^{*''} - y1^*] + [y2 - y1^{*''}] \\
&\quad + [y2^{*''} - y2^{*''}] \\
&= [y1^* - y1] + [y1^{*''} - y1^*] \\
&\quad - [y2^{*''} - y2] + [y2^{*''} - y1^{*''}] \\
&= \{[y1^* - y1] - [y2^{*''} - y2]\} \\
&\quad + [y1^{*''} - y1^*] + [y2^{*''} - y1^{*''}] \\
&= \{TI1 — TI2\} + TC + \Delta y_x
\end{aligned}
$$

where

$y2 - y1$ = output growth
$TI1 - TI2$ = technical efficiency change
$TC$ = technical change and
$\Delta y_x$ = output growth due to input growth.

The decomposition in equation (5) enriches Solow's dichotomy by attributing observed output growth to movements along a path on or beneath the production frontier (input growth), movement toward or away from the production frontier (technical efficiency change), and shifts in the production frontier (technological progress).

## TFP Growth Components

Following the conventional conceptualization of total factor productivity, the TFP growth can be defined as the growth in output not explained by input growth. Thus from equation (5), TFP growth consists of two components: technical efficiency and technical changes; that is,

$$(6)\quad TFP = (TI1 - TI2) + TC.$$

Now, TFP growth in equation (6) between period ($t$—1) and $t$ for the $i$th firm can be estimated as

$$
\begin{aligned}
(7)\quad \Delta TFP_i &= \ln\left(\frac{TFP_{i,t}}{TFP_{i,t-1}}\right) \\
&= \{(y1^{*X1}_{i,t-1} - y1^{X1}_{i,t-1}) - (y2^{*''X2}_{it} - y2^{X2}_{it})\} \\
&\quad + (y1^{*X1}_{it} - y1^{*X1}_{i,t-1})
\end{aligned}
$$

where $y1^{*X1}$ and $y2^{*''X2}$ (in logarithms) are, respectively, the frontier outputs calculated using $X1$ (period 1) and $X2$ (period 2) input levels (see figure 1). These two TFP components are analytically distinct and may have quite different policy implications (Nishimizu and Page). High rates of technological progress, on the one hand, can coexist with deteriorating technical efficiency performance. Relatively low rates of technological progress can also coexist with an improving technical efficiency performance, on the other hand. As a result, specific policy actions are required to address the difference in the sources of variation in productivity.

The technological change component of productivity growth captures shifts in the frontier technology and can be interpreted as providing a measure of innovation. This decomposition of total factor productivity growth into technical efficiency improvement (catching-up) and technological change is, therefore, useful in distinguishing innovation or adoption of new technology by "best practice" firms from the diffusion of technology. Coexistence of a high rate of technological progress and a low rate of change in technical efficiency may reflect the failures in achieving technological mastery or diffusion.

## Empirical Illustration

The workability of the above suggested method has been demonstrated in the following pages by examining the TFP growth before and after reforms in China.

### *Data*

The provincial-level data used in this empirical illustration consist of observations from twenty-eight of the twenty-nine provinces in mainland China covering the periods 1970-1987.[5] Gross agricultural production value serves as the aggregate total output. The subaggregates are (*i*) crop production, (*ii*) forestry, (*iii*) animal husbandry, (*iv*) sideline industries, and (*v*) fisheries. Values of crop output for each province are calculated from the physical outputs of seven grain crops and twelve cash crops, using official prices of 1980 as weights for aggregation. Nationally, these nineteen crops accounted for 92% of total acreage and 72.5% of the cropping sector's output value in 1980. Inputs in the data set include four categories: land, labor, machinery, and chemical fertilizer. Land refers to sown acreage and pasture areas (calculated in sown land area equivalence). Labor refers to the workers in the cropping sector. Machinery includes tractors and draft animals measured in horsepower. Chemical fertilizer refers to the gross weight of nitrogenous, phosphate, and potash fertilizers that each province consumed in each year.

### *Temporal Province-Specific Production Functions*

Let the production technology be represented by a Cobb-Douglas function. Using time-specific dummies, $D$, to account for interyear differences, we can express in logarithmic form the temporal firm-specific production function as[6]

[5] We are grateful to Justin Lin for providing this data set.

[6] To facilitate comparisons, we have adopted the structure of inputs followed in Fan and Lin.

$$(8) \qquad \ln Y_{it} = \alpha_{1i} + \sum_{j=2}^{18} \gamma_{jt} D_{jit} + \sum_{k=2}^{5} \alpha_{ki} \ln X_{kit}$$

$$i = 1, \ldots, 28 \text{ and } t = 1(1970), \ldots, 18(1987)$$

where

$$\alpha_{1i} = \bar{\alpha}_1 + u_{1i};\ D_{jit} = 1 \text{ if } j = t \text{ and zero otherwise,}$$

and

$Y$ = aggregate total agricultural output using the 1980 constant prices,
$X_2$ = land (sum of sown areas and pastures) in hectares,
$X_3$ = labor measured by the number of employed persons at year end,
$X_4$ = machinery measured by total horsepower at year end, and
$X_5$ = chemical fertilizer measured in kg.

### *Empirical Results*

For a given $t$, employing the specifications and estimation procedures described in the preceding section, the variance-covariance matrix of the random components of the $\gamma$'s and $\alpha$'s as in equation (8), their means, and individual response coefficients were obtained. From these estimates, frontier outputs for each period $t$ were calculated. Finally, the TFP growth for each province was obtained as shown in equation (7) for periods 1970–78, 1978–84, and 1984–87. The results are presented in table 1. The TFP growth in the three periods reflect interesting responses of the farmers to policy changes in China. The figures suggest that the prereform collective farming system was basically a failure. Twenty out of twenty-eight provinces experienced a negative growth in TFP. However, the situation changed after 1978 when the government introduced the household responsibility system. A significant increase in TFP growth in the post-1978 period (table 1) suggests that the institutional rural reform in the cropping sector was indeed successful. These results are also in conformity with previous findings by other studies, though they used different methodologies (e.g., Fan and Lin). Lin, for example, estimated that almost half of the 42.2% growth of output in the cropping sector during 1978–84 was driven by productivity change due to reforms. In the same study, Lin found that almost all of the productivity growth was attributable to changes resulting from the introduction of the household responsibility system.

**Table 1. Total Factor Productivity (TFP) Growth in Chinese Agriculture**

| Province | 1970–78 | 1978–84 | 1984–87 |
|---|---|---|---|
| 01 Beijing | −0.1774597 | 0.0545519 | −0.0843488 |
| 02 Tianjin | −0.1464745 | 0.0207088 | −0.1039874 |
| 03 Hebei | −0.0534147 | 0.0150848 | −0.1038479 |
| 04 Shanxi | −0.0142500 | 0.1130137 | 0.0542956 |
| 05 Inner Mangolia | −0.1330762 | 0.1415206 | −0.0436170 |
| 06 Liaoning | −0.0313965 | 0.3270978 | 0.1258757 |
| 07 Jilin | 0.1870640 | 0.2910597 | −0.1857607 |
| 08 Heilongjiang | −0.1636995 | 0.0196935 | 0.2125631 |
| 09 Shanghai | −0.0986042 | 0.0220964 | 0.1135779 |
| 10 Jiangsu | −0.0480903 | 0.1743175 | −0.1312817 |
| 11 Zhejiang | 0.0257713 | 0.0572908 | −0.0785916 |
| 12 Anhui | 0.0609980 | 0.1453753 | −0.0370694 |
| 13 Fujian | 0.0390747 | 0.1069434 | −0.0644466 |
| 14 Jiangxi | −0.0168963 | 0.0925243 | 0.1334151 |
| 15 Shandong | 0.0018006 | 0.0593325 | 0.0866208 |
| 16 Henan | −0.0226773 | 0.0360007 | 0.0449647 |
| 17 Hubei | −0.2677729 | −0.2245552 | 0.0533284 |
| 18 Hunan | −0.0621654 | −0.0389523 | −0.0004668 |
| 19 Guangdong | −0.1095815 | 0.0939913 | 0.0527980 |
| 20 Guangxi | 0.0454310 | 0.2454689 | 0.1082643 |
| 21 Sichuan | 0.0275182 | 0.4249694 | 0.3272682 |
| 22 Guizhou | −0.5185472 | 0.4779702 | 0.3062147 |
| 23 Yunnan | 0.0972935 | 0.1325035 | −0.0174693 |
| 24 Shaanxi | −0.2202377 | 0.3302985 | −0.0661435 |
| 25 Gansu | −0.1108752 | 0.0316080 | −0.0246953 |
| 26 Qinghai | −0.0743706 | 0.0419432 | −0.0132088 |
| 27 Ningxia | −0.1184637 | 0.1089034 | −0.0176883 |
| 28 Xinjiang | −0.0036206 | 0.0548683 | −0.0322813 |
| National | −0.0556782 | 0.0765784 | 0.0276853 |

The last column of table 1 shows that the TFP growth stagnated or declined during the period 1984–87, after seven years of positive growth. Some authors argue that the dynamism which was released by the institutional reforms had fully worked its way into production and there was no alternative source of strong productivity growth from the mid 1980s. Nevertheless, the decomposition of TFP growth into technical efficiency change and technological progress does help to understand or explain these changes.

The analysis suggests that the prereform output growth came almost exclusively from input growth.[7] On the other hand, the results reveal that output growth, induced by reforms between 1978 and 1984, can be attributable to productivity growth, of which technical efficiency is the most dominant component (figure 2). After 1984, however, a different picture emerged. Technical efficiency either stagnated or declined. There were at least five explanations for the deterioration in technical efficiency during 1984–87. First, the rapid development of township and village enterprises significantly increased the opportunity cost of farming, which lead to a shift in the labor force, particularly educated and younger farmers and other resources from the cropping sector to other activities. Second, facing a decline in the grain output in 1985, the government retreated from the early position, and voluntary procurement contract was made mandatory again (Lin). Third, throughout 1985–91, government intervention in the market and production was actually intensified which resulted in the deviation of regional comparative advantages. Fourth, the introduction of the contract purchase system in 1985 resulted in lower real procurement prices, which until then had been consistently rising. This aspect of pricing had a negative effect on farmers' incentive to work efficiently. Fifth, the deterioration of land infrastructure, particularly the existing water conservation systems, kept farmers from applying the best production tech-

[7] According to Lin, the most important source of growth from inputs was the increase in the application of chemical fertilizers.

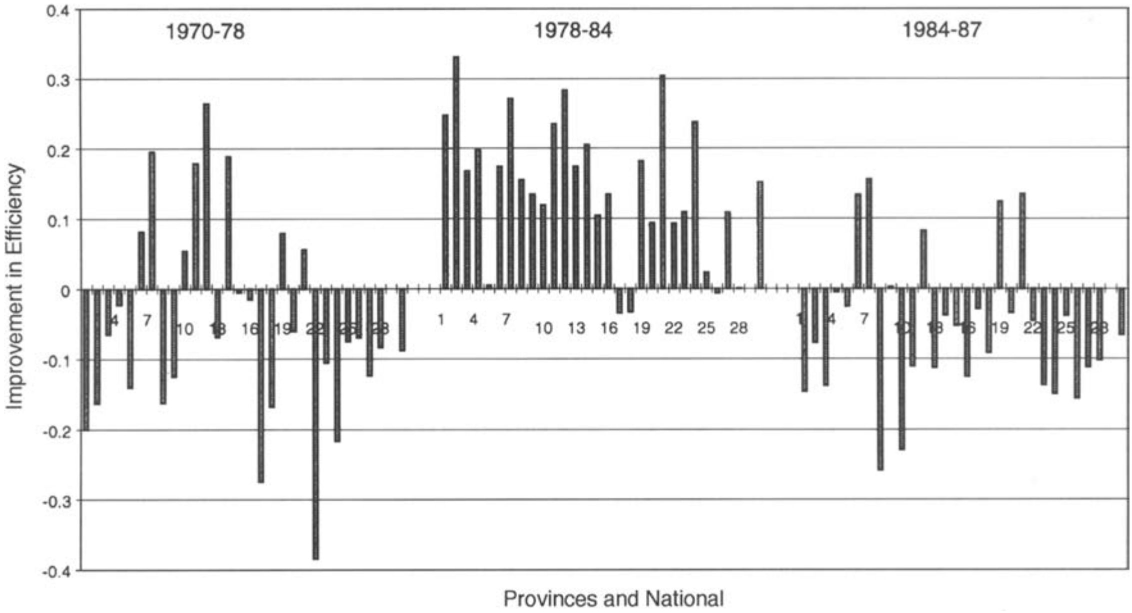


**Figure 2. Technical efficiency in Chinese agriculture, 1970–87**

niques. These combined factors led to the decline in technical efficiency.[8]

The above findings have significant policy implications for promoting production growth in China's cropping sector. For example, as Fan argued, without an increase in land areas, an increase in labor will have only a limited effect on total production. Increased use of modern inputs, especially chemical fertilizers and mechanization of irrigation, is likely to have the greatest potential for increasing total production. An increase in agricultural investments, especially in research and development, is needed to stimulate technical change. The institutional changes should also focus on greater regional specialization based on comparative advantage. For example, crops should be grown where soil and climate provide the most favorable conditions.

## Conclusion

In this paper we suggest and empirically demonstrate a method of measuring TFP growth within the varying coefficients production frontier framework developed in Kalirajan and Obwona. In the Solow "residual" approach, firms are assumed to be 100% technically efficient, and TFP, which in this case is equivalent to the technological change, is measured as the residual. The conventional TFP components approach based on a stochastic frontier production function, on the other hand, explicitly recognizes the fact that TFP growth consists of two distinct components: technical efficiency change and technical progress. However, this approach treats technical progress as neutral and is obtained as the residual following the growth-accounting procedures. One of the advantages of the suggested method is that it avoids the restrictive assumptions inherent in both the Solow "residual" and the conventional stochastic-frontier-based TFP components approaches discussed above. In the method followed in this paper, the two TFP components—technical efficiency change and technical progress—are first estimated separately. The sum of the two components is then subtracted from the total output growth to yield the input growth component as the residual. Thus, the total input growth component itself is not actually calculated as in the Solow "residual" or in the conventional stochastic-frontier-based TFP components approaches. This has a distinct advantage of avoiding the problems usually encountered in estimating the total input growth component, such as input omission and adjustment for input quality changes.

The suggested method provides important

[8] We are thankful to an anonymous reviewer for sharpening these arguments.

complementary information with traditional approaches to productivity measurement. It provides a means to measure the phenomenon of catching up (with the frontier) and also of innovation (shifts in the frontiers). Finally, the measures of TFP and output growth components not only provide more insights and better understanding of the dynamic nature of the production processes, but also have important policy implications. For example, policy actions intended to improve the rate of total factor productivity growth might be misdirected if they focus on accelerating the rate of innovation in circumstances where the cause of total factor productivity change could be due to the low rate of technology diffusion (technical inefficiency).

The suggested method has been applied to Chinese provincial-level agriculture data to examine the total factor productivity growth before and after reforms in China. The analysis in this paper shows that TFP growth in the prereform period was negative in twenty out of twenty-eight provinces and that it was positive in almost all provinces during the reform periods of 1978–84, while negative in sixteen out of twenty-eight provinces in the postreform periods of 1984–87. In conformity with earlier studies, detailed results indicate that replacing the collective farming system with a household-based contract system did substantially improve technical efficiency of Chinese farmers, which is one of the components of TFP. However, the results also reveal that technical efficiency either stagnated or declined during the postreform periods of 1984–87. The implication is that Chinese agricultural growth during 1984–87 could have been further increased by continuing the earlier reform measures.

The limitations of this study should be borne in mind while analyzing the empirical results. The major limitation is that a firm-level efficiency concept has been applied to regional level data.[9] If individual farms were used, the results could have been more effective. Nevertheless, the present results can be interpreted as the mean efficiency measures of farms within the concerned regions.

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[9] We are grateful to an anonymous reviewer for pointing out this limitation.

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