Ind. Jn. of Agri. Econ.
Vol. 60, No. 1, Jan.-March 2005

ARTICLES

Total Factor Productivity Growth of Wheat in India: A Malmquist Approach

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I

INTRODUCTION

Agriculture in India, one of the most successful sectors of the national economy in terms of productivity growth, had more than compensated for the rapid growth in demand for the past few decades. The series of interventions[1] initiated in the mid-1960s, that led to the Green Revolution in cereals production transformed the country from one of food deficiency to self-sufficiency. The transformation has taken place since the introduction of new technology in the form of fertiliser responsive high yielding varieties (HYVs) in 1966-67. The increase in the consumption of modern inputs like HYVs seeds, agrochemicals like fertilisers, pesticides, etc., and irrigation as also in the use of agricultural machinery, have been equally steep, breaking the age-old style-hold of traditional and subsistence agriculture. The progress has been hailed as revolution, popularly known as "Green Revolution". But the headway, arising out of technical changes and improvements in efficiency in the production has been slowed down. The compound growth rates in respect of production and productivity of principal crops present a gloomy picture for the post-macro reform years of the 1990s (Table 1).

TABLE 1. COMPOUND GROWTH RATES OF PRODUCTION AND PRODUCTIVITY OF PRINCIPAL CROPS IN INDIA FROM 1981-82 TO 2000-01

(per cent per year)

	Production		Productivity	
Crops (1)	1981-82 to 1989-90 (2)	1990-91 to 2000-01 (3)	1981-82 to 1989-90 (4)	1990-91 to 2000-01 (5)
Wheat	3.57	3.27	3.10	2.21
Rice	3.55	1.74	3.47	0.92
Total cereals	3.03	1.86	2.90	1.36
Total pulses	1.52	-0.04	1.61	0.55
Total foodgrains	2.85	1.66	2.74	1.28

Source: Agricultural Statistics at Glance, 2001, Government of India, New Delhi.

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The author gratefully acknowledges his superior Abhijit Sen for providing the data and research inputs. The author is thankful to the anonymous referee for the valuable comments provided on his paper.

After enjoying the fruits of Green Revolution, a decline in the rate of growth of foodgrain production has been observed during the recent past in respect of productivity and input response of factor productivity (Table 1). Rice production and productivity increased at an annual compound growth rate of 3.55 and 3.47 per cent in the 1980s, which fell, respectively to 1.74 and 0.92 per cent in the 1990s. Also the wheat production and productivity decreased respectively from 3.57 per cent and 3.10 per cent in the 1980s to 3.27 per cent and 2.21 per cent in the 1990s.

The tremendous success of Green Revolution were triggered by the development and release of modern, semi-dwarf, high-yielding varieties (HYVs) of wheat, in the 1960s across the world, and India in particular. Yields in India have increased sharply in the initial periods of Green Revolution. However, there is a slowdown in the rate of growth in both the production and productivity in the recent decade of the 1990s. It assumes considerable interest to estimate the rate of total factor productivity growth of wheat in India. The major wheat growing states in India are Uttar Pradesh, Rajasthan, Madhya Pradesh, Punjab and Haryana. The major wheat growing areas are all in the north, and therefore, unlike rice, wheat has a relatively narrow geographic land base of production. Wheat is a temperate crop requiring low temperatures, and most of the country is tropical. Even within many of these states the wheat areas are limited and overall only about 18 per cent of the net cropped area is planted under wheat. Again Uttar Pradesh contributes the largest share with 36 per cent of production, followed by Punjab with 19 per cent and Haryana with 11 per cent. These three northern states together contribute two-thirds of the production of wheat. These are followed by Madhya Pradesh 11 per cent, Rajasthan 10 per cent. All the rest contribute only 13 per cent.

This study uses non-parametric approach to estimate productivity growth in the wheat production in the major producing states of India from 1982-83 to 1999-2000. The states chosen for the study are: Punjab and Haryana (where Green Revolution have made a significant progress); Uttar Pradesh (which has a made a moderate progress with the Green Revolution); and Rajasthan and Madhya Pradesh (which have been lagging behind). The productivity change in wheat production is decomposed into technical change and efficiency change using the Data Envelopment Analysis (DEA). This technique allows us to isolate the contributions of improving efficiency from the contribution of technological progress.

The rest of this paper is organised as follows: the next section presents a review of previous studies on Indian agricultural productivity and efficiency. The third section discusses productivity, economic efficiency, and their measurements. This section also outlines the Malmquist productivity index. The DEA approach to measuring wheat production efficiency and productivity is elaborated in this section. The data and their sources are described in the fourth section. The fifth section discusses the results and the implications for the study. Summary and conclusions are included in the last section.

II

PRODUCTIVITY AND EFFICIENCY IN INDIAN AGRICULTURE

Indian agriculture has witnessed tremendous changes during the past several decades following the adoption of Green Revolution technology since the mid-1960s. The sources and effects of these technical changes on Indian agricultural productivity have been of considerable interest to many economists. Also the estimates of India's agricultural productivity have been controversial and debatable. The differences in the estimation methods and reliability in the statistics gave rise to many debates on the trend of India's agricultural productivity.

Jha and Evenson (1973) estimated the rate of Total Factor Productivity Growth (TFPG) in Indian agriculture as a whole to be 0.8 per cent per year during the 1956-1961 periods, a mere 0.3 per cent per year during 1961-1965, but 2.3 per cent during 1965-1971. The jump in the TFPG in the latter period clearly reflects the Green Revolution whereas Becker *et al.,* (1992) found a decline in TFPG in Indian agriculture from an annual rate of 0.2 per cent during 1960-64 to -0.2 per cent during 1965-71. However, they estimated that it jumped to 1.4 per cent during 1972-77, and then was negative again as -0.9 per cent during 1978-81. Rosegrant and Evenson (1992) estimated TFP growth rates for India as a whole of 0.8 per cent per year during 1957-65, 1.2 per cent during 1965-75, and 1.0 per cent during 1975-85. However, due to the non-availability of input allocation data on individual crops, this may under- or over-estimate the TFP. Arnade (1998) used the DEA method to calculate the Malmquist Productivity Indexes (MPI) for the agricultural sectors of 70 countries, which includes India, from 1961 to 1993. He estimated that output grew by 2.55 per cent and inputs like tractors and fertiliser use grew by 11.55 per cent and 8.67 per cent respectively. But the productivity has shown a negative growth of -2.60 per cent during 1961-1993. Murgai *et al.* (2001) attempted to determine the long-term productivity and sustainability of irrigated agriculture in the Indian and Pakistan Punjab by measuring trends in total factor productivity for production systems in both states since the advent of Green Revolution. The period, they took, for Indian and Pakistan Punjab were 1961-94 and 1966-94, respectively. Using Törnqvist-Theil index to measure total factor productivity, they found that despite a higher output growth (5.5 per cent and 3.2 per cent in Indian and Pakistan Punjab, respectively) and crop yields in Indian Punjab, productivity growth (1.9 per cent and 1.3 per cent in Indian and Pakistan Punjab, respectively) was higher by a small margin. Moreover, the lowest growth in productivity took place during the initial Green Revolution period (as opposed to the later intensification and post-Green Revolution periods) and in the rice-wheat system in both the states. Using simple index method for the estimation of TFPG for farm level production data for 300 randomly selected farmers producing wheat, Sidhu and Byerlee (1991), for the period 1971-72 to 1986-87, found that TFP for wheat in Punjab was basically stagnant during the period under study. They also observed that the labour-saving technologies are the major sources of productivity growth in the period. However, they have not examined the resource base changes which could have shown the sustainability of the production. Evenson *et al.* (1999) estimated the Törnqvist-Theil index, and calculated the annual growth rates in TFP in the crop sector, by agro-climatic zone, based on three-year moving averages for the periods, 1956-65, 1966-76, 1977-87, and 1956-87 as 1.10 per cent, 1.39 per cent, 1.05 per cent, and 1.13 per cent, respectively.

However, the above mentioned studies of TFPG in Indian agriculture have not distinguished the increment in productivity that occurs from technical progress and from that which results from improved technical efficiency in the application of the already established technologies. This is because the technically efficient production can be achieved if farmers follow the best practice to apply the technology. To the extent that farmers do not produce with technical efficiency due to differences in their capacity to use new technological knowledge, technical progress is not the only source of total factor productivity growth. Changes in productivity arise from two connected parts: technical progress and changes in efficiency. Hence, the decomposition of total factor productivity growth into technical progress and changes in efficiency provides more information about the application of production technology. From a policy point of view this decomposition is important to understand the unused potential of existing technology.

Kalirajan and Shand (1997) decomposed output growth into input growth,[2] technical change and efficiency change for the period 1980-83, 1984-87, and 1988-90, and estimated technical change as a shift in production frontiers. Allowing technical progress to be non-neutral, they estimated TFPG the stochastic varying coefficient frontier using Cobb-Douglas technology function for the period 1980-90. Their analysis shows that TFPG was negative in 4 out of 15 states in 1980-83 and that, by the end of the decade, it was small for those states where the contribution of TFPG was positive. For the front-runner states like, Punjab and Haryana the TFP growth declined from 64.45 per cent and 54.82 per cent during 1980-83 to 45.24 per cent and 33.22 per cent respectively, whereas for Uttar Pradesh, Rajasthan, and Madhya Pradesh it slumped from 56.41 per cent, 53.35 per cent, and -28.42 per cent during 1980-83 to 38.58 per cent, 32.55 per cent, and -32.67 per cent during 1988-90 respectively. While the input growth contributed more than 50 per cent to the output growth, the contribution of technology to output growth declined substantially, particularly from 1988 to 1990. The share of fertiliser and electricity in the consumption of core inputs, which enjoy heavy subsidies in Indian agriculture, increased from 16.8 per cent in the seventies to 29.2 per cent in the eighties. An average of only around 18 per cent could be attributed to technological change in the pre-reform period but more to gains in technical efficiency. Importantly, the contribution of increasing technical efficiency to output growth remained more or less at the same levels in most states in the pre-reform periods. Thus since the introduction of the HYVP, Indian agriculture experienced low rates of technological progress together with negligible improvements in technical efficiency, and output growth in the sector became increasingly dependent on input growth. Their results, obviously, suffer from the problem of excessive aggregation. It would be desirable to conduct estimation at a lower level of aggregation, given India's big size and enormous diversity in the agro-climatic conditions.

This paper attempts to extend this literature in several directions. Firstly, we employ an alternative approach to production frontier estimation. Using the econometric approach, all previous studies have to assume a specific form of production function. If the functional form is incorrect, the estimation will be spurious.[3] In contrast, the DEA employed to measure Malmquist index in this study is a non-parametric estimation method under which assuming the form of the production function is not necessary. The decomposition of Malmquist productivity index allows us to identify the combinations of improved efficiency and technical progress. Its major shortcoming is, however, that tests of significance of the estimation as those in the econometric approach cannot be carried out. Secondly, all the previous studies provide an analysis of India's agricultural productivity up to the early 1990s. Investigation of the situation in the 1990s or post-macro reform period is conspicuously absent. This study examines India's agricultural productivity in 1981-2000. Although it concentrates on wheat crop only, it may also shed some light on the changes at the national level for other crops too. Lastly, most of the earlier studies had taken land as one of the inputs, besides other traditional and modern inputs. However, land distribution in India is highly skewed and diverse, thus the estimation of TFPG may not reflect the true picture. This study has taken output per hectare and intends to do away with the land. Again, to avoid the incongruity in the price information, the quantity data has been used in the study.

III

METHODOLOGICAL FRAMEWORK

Productivity is generally defined in terms of the efficiency improvement and technical change with which inputs are transformed into outputs in the production process (Chambers, 1988; Coelli *et al.,* 1998). Farrell (1957), as mentioned in Førsund and Sarafogulu (2000), defined two types of production efficiency: technical efficiency (TE) which evaluates a firm's ability to obtain the maximum possible output from a given set of inputs, and allocative efficiency (AE) which measures a firm's ability to maximise its profits by comparing marginal revenue product with marginal costs of inputs. Traditionally the Stochastic Frontier Approach (SFA) is used to measure the TE and AE, given the technology and prices. However, this econometric approach requires the specifications of production function technology. Recently, mathematical programming approaches, such as Data Envelopment Analysis (DEA) are developed to measure TE by combining the firm's production to the best production frontier (Seiford and Thrall, 1990).

Productivity can be conceptualised into two main components: partial factor productivity and total factor productivity (TFP). Partial productivity, also called average product, is defined as the rate of output to a specific input. Let Y be the output, x_i denoted as any individual input factor, then the average product (AP_i) of the input x_i is

$$AP = \frac{Y}{x_i} \quad \text{.... (1)}$$

It only measures the contribution of one particular input to technical change, ignoring the effects from the other inputs. TFP is defined as the average product of all input factors. It is the ratio of output to the index of inputs. If X denotes the index of all inputs, then TFP is

$$TFP = \frac{Y}{X} = \frac{Y}{\Sigma \alpha_i \, x_i} \quad \text{.... (2)}$$

where α_i is the weight of input x_i.

TFP can be calculated as by estimating aggregate production function or cost functions with limited functional forms and imposed restrictions on the econometric parameters. It can also be measured using indices, such as Laspeyers, Paasche, Fisher, or Törnqvist-Theil indices. Index approach imposes restrictions on production technology by putting weights on inputs and outputs. Indices of productivity, therefore, are simply the ratios of an aggregate output index to an index for total factor use. The most popular form for estimating TFP growth in the past is the Törnqvist-Theil index. The Törnqvist-Theil index calculates TFP growth based on information concerning prices, and uses cost/revenue shares as weights to aggregate inputs/outputs. However, when calculating the Törnqvist-Theil index, the observed output is assumed to be equivalent to frontier output. Consequently, decomposition of the TFP growth into the movements towards (efficiency improvement) and shifts in the production frontier (technical change) is not possible. On the other hand, the Malmquist index has gained considerable popularity in recent years. In this regard, Färe *et al.* (1994 a) applied the linear-programming approach to calculate the distance functions that make up the Malmquist index. Compared to the other methods, the approach has four major advantages (Färe *et al.,* 1994 b): First, since it is calculated from distance functions, it only requires data on quantities and thus less data demanding than the Törnqvist-Theil index. Second, it allows for inefficient performance and does not presume an underlying functional form of the production technology. Third, no assumption regarding the optimising behaviour of the producer is necessary. And fourth, since it is a non-parametric index, it does not require econometric estimation. The chosen type of index number then allows decomposition of changes in productivity into technical progress and efficiency changes.

This study applies the generalised Malmquist index, developed by Färe *et al.* (1994 a), to measure the contribution from the progress in technology and improvement in technical efficiency in the growth of productivity in Indian agricultural production. The Malmquist productivity index (MPI) were proposed by

Caves *et al.* (1982) based on distance functions developed by Malmquist (1953). Fare *et al.* (1994 a) decomposed into two mutually exclusive components: technical change and efficiency change over time. They calculated the productivity change as the geometric mean of two MPI using output distance functions.

Let the production technology S^t for each time period t = 1,2,…T denotes the transformation of inputs, $x^t \in R^N_{++}$ into outputs, $y^t \in R^M_{++}$.

$$S^t = \{ (x^t, y^t) : x^t \text{ can produce } y^t \} \qquad \text{…. (3)}$$

where S^t is assumed to satisfy the required axioms to define the meaningful output distance functions (Färe *et al.*, 1994 b). Following Färe *et al.* (1994 b), the output distance function[4] in time period 't' is defined as

$$D_0^t(x^t, y^t) = \inf\left\{\theta : (x^t, \frac{y^t}{\theta}) \in S^t\right\} = \left[\sup\{\theta : (x^t, \theta y^t) \in S^t\}\right]^{-1} \qquad \text{…. (4)}$$

Distance function is defined as the inverse of the maximal proportional increase of the output vector y^t, given inputs x^t. It is also equivalent to the reciprocal of Farrell's (1957) measure of output efficiency, which measure TFP "catching-up" of an observation (states in our case) to the best practice frontier technology. In this study, the practice frontier is the highest productivity observed in the states in India.

$D_0^t(x^t, y^t) = 1$ if and only if (x^t, y^t) is on the boundary or frontier of technology and production is technically efficient.

$D_0^t(x^t, y^t) < 1$, the production at t is interior to the frontier the degree of technical inefficiency. The output distance function in time period t+1, $D_0^{t+1}(x^{t+1}, y^{t+1})$, can be defined as (4) with 't' replaced by t+1.

Let us define output distance with respect to two different time periods as

$$D_0^{t+1}(x^{t+1}, y^{t+1}) = \inf\left\{\theta : (x^{t+1}, \frac{y^{t+1}}{\theta}) \in S^{t+1}\right\} \qquad \text{…. (5)}$$

This is one mixed index that measures the maximal proportional change in outputs y^{t+1} given inputs x^{t+1}, under the technology at time period t+1. Following Caves *et al.* (1982), the MPI is defined as

$$M_0^t = \frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)} \qquad \text{…. (6)}$$

This ratio index measures the productivity changes originating from changes in technical efficiency at time period 't' and time period t+1 under the technology in time period 't'. The technical efficiency changes from time period t to t+1 can also be measured under the technology in time period t+1. This Malmquist index can be defined as

$$M_1^{t+1} = \frac{D_1^{t+1}(x^{t+1}, y^{t+1})}{D_1^{t+1}(x^t, y^t)} \quad \text{.... (7)}$$

Färe *et al.,* (1994 a) specified the output-based Malmquist productivity change index as the geometric mean of (6) and (7) and decomposed into two parts:

$$M_0(x^{t+1}, y^{t+1}, x^t, y^t) = \left[\left\{\frac{D_0^t(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}\right\}\left\{\frac{D_1^{t+1}(x^{t+1}, y^{t+1})}{D_1^{t+1}(x^t, y^t)}\right\}\right]^{\frac{1}{2}}$$

$$= \frac{D_1^{t+1}(x^{t+1}, y^{t+1})}{D_0^t(x^t, y^t)}\left[\left\{\frac{D_0^t(x^{t+1}, y^{t+1})}{D_1^{t+1}(x^{t+1}, y^{t+1})}\right\}\left\{\frac{D_0^t(x^t, y^t)}{D_1^{t+1}(x^t, y^t)}\right\}\right]^{\frac{1}{2}}$$

$$= E(x^{t+1}, y^{t+1}, x^t, y^t) \times T(x^{t+1}, y^{t+1}, x^t, y^t) \quad \text{.... (8)}$$

where E (.) refers to the relative efficiency change under the constant returns to scale (CRS) which measures the catching-up to the best practice frontier for each observation between two time period, t and t+1, and T(.) represents the technical change measures the shift in the frontier of technology (or innovation) between two time periods evaluated at x^t and x^{t+1}. Efficiency and technical change indices exceeding unity indicates gains in those components. Further, the relative efficiency change under the CRS, E (.), can be decomposed into two components as:

$$E(.) = \frac{D_1^{t+1}(x^{t+1}, y^{t+1})_{CRS}}{D_0^t(x^t, y^t)_{CRS}}$$

$$= \frac{D_1^{t+1}(x^{t+1}, y^{t+1})_{VRS}}{D_0^t(x^t, y^t)_{VRS}}\left[\frac{D_0^t(x^t, y^t)_{VRS}}{D_0^t(x^t, y^t)_{CRS}} \times \frac{D_1^{t+1}(x^{t+1}, y^{t+1})_{CRS}}{D_1^{t+1}(x^{t+1}, y^{t+1})_{VRS}}\right] \quad \text{.... (9)}$$

The pure efficiency change, PECH (the first term outside the bracket) measures change in technical efficiency under the assumption of VRS technology, whereas, the scale efficiency change, SCH (term in brackets) measures the changes in efficiency due to movement toward or away from the point of optimum scale. Scale efficiency in a given period captures the deviations between the VRS technology and the CRS technology at observed inputs. The decomposition of the MPI allows us to identify the contribution of catching-up in efficiency and innovation in technology to TFP growth. According to Färe *et al.* (1994 b), MPI greater than one indicates growth in productivity and less than one shows decline. In addition, improvements in any one of the two components of the MPI are also associated with values greater than one, and decline are also associated with values less than one.

Färe *et al.* (1994 a) used Data Envelopment Analysis (DEA) methods to estimate and decompose the MPI. The DEA method is a non-parametric approach in which the envelopment of decision-making units (DMU) can be estimated through linear programming methods to identify the "best practice" for each DMU. The efficient units are located in the frontier and the inefficient ones are enveloped by it. Four linear programmings (LPs) must be solved for each DMU to obtain the distances defined in equation (4) and they are:

$$[D_0^t(x^t, y^t)]^{-1} = \max_{\theta,\lambda} \theta, -\theta y^t + Y^t\lambda \geq 0, \quad x^t - X^t\lambda \geq 0, \lambda \geq 0, \qquad \text{.... (10)}$$

$$[D_0^{t+1}(x^{t+1}, y^{t+1})]^{-1} = \max_{\theta,\lambda} \theta, -\theta y^{t+1} + Y^{t+1}\lambda \geq 0, \quad x^{t+1} - X^{t+1}\lambda \geq 0, \lambda \geq 0, \qquad \text{.... (11)}$$

$$[D_0^t(x^{t+1}, y^{t+1})]^{-1} = \max_{\theta,\lambda} \theta, -\theta y^{t+1} + Y^t\lambda \geq 0, \quad x^{t+1} - X^t\lambda \geq 0, \lambda \geq 0, \qquad \text{.... (12)}$$

$$[D_0^{t+1}(x^t, y^t)]^{-1} = \max_{\theta,\lambda} \theta, -\theta y^t + Y^{t+1}\lambda \geq 0, \quad x^t - X^{t+1}\lambda \geq 0, \lambda \geq 0, \qquad \text{.... (13)}$$

Here, K, N, M, and T represent the number of states, inputs, outputs, and time periods in the sample respectively. Scalar θ represents the proportional expansion of output vector, given the input vector, $\lambda = [\lambda_1, \lambda_2, \ldots, \lambda_K]$ denotes the $K \times 1$ vector of constants, which represent peer weights of a state. The variables y^t and x^t represent the $M \times 1$ output vector and $N \times 1$ input vectors respectively in period 't'. Y^t and X^t denote, respectively, the $M \times K$ output matrix and $N \times K$ input matrix, containing the data for all states in period 't'. The notations for t+1 period are defined in a similar fashion. Equations (10) and (11) measure the technical efficiency of the i-th state in period t and t+1 respectively. In equations (12) and (13), the i-th observation from period t+1 compares the technology constructed using the period t+1 data, and vice versa. Following Afriat (1972), the assumption of CRS may be relaxed to allow VRS by adding the restrictions N1'λ = 1 in each of the above LPs (equation 10 to 13). Here, N1 is an $N \times 1$ vector of ones. Here we have used VRS as the reference technology in computing the productivity indexes.

The above four linear programmes (LPs) are required for each production unit (states in our study) in each pair of study. Thus if one has data on K units over the time periods, one must solve $K \times$ (4T-2) LPs to solve the required chained indices for the estimation of Malmquist index (Coelli *et al.*, 1998, p. 228). For example, with N=5 states and T=19 time periods, this would involve 370 LPs. We have used the econometric package DEAP 2.1 written by Tim Coelli (1996) to derive the results.

IV

DATA

Data used for the analysis are state-level aggregates on input use and outputs collected under the *Comprehensive Scheme for Studying Cost of Cultivation of Principal Crops* by the Directorate of Economics and Statistics, Ministry of Agriculture (various volumes) for the period 1981-82 to 1999-2000.[5] The missing year data on inputs use and yields per hectare are predicted using the interpolation based on the trends available in the data. The output and inputs used in the study are in quantities to avoid the anomalies in price information: Output (in kg), Seeds (in kg), Human Labour (HL, in hrs), Animal labour (AL, in p.h.), Chemical input include chemical fertiliser (CHEM, in kg). Irrigation variable is constructed as the ratio of acreage under wheat (irrigated) to the net sown area (IRR in per cent) and machine labour (MACH) per hectare is computed by dividing the machine labour cost per hectare by the price indices of the same.[6] In fact one of the important advantages of non-parametric DEA approach is that it does not need price information. The mean of the input and output data used in the study has been presented in Table 2 for the pre- and post-macro reform periods.

TABLE 2. SUMMARY OF THE MEAN OF INPUTS AND OUTPUT IN THE PRE-MACRO (1980s) AND POST-MACRO (1990s) REFORM PERIOD

States (1)	Years (2)	Seed (3)	HL (4)	AL (5)	CHEM (6)	MACH (7)	IRR (8)	Yield (9)
Rajasthan	1980s	125.7	583.3	105.0	50.8	271.4	96.0	2,287.7
	1990s	139.3	565.9	47.3	86.2	434.6	98.0	3,069.6
Madhya Pradesh	1980s	107.3	375.7	127.5	42.1	96.1	39.3	1,295.2
	1990s	116.8	373.5	56.6	76.2	263.9	67.6	1,755.5
Uttar Pradesh	1980s	126.1	590.4	129.0	103.3	340.8	86.3	2,460.8
	1990s	135.3	522.0	56.8	132.2	458.0	91.8	3,029.5
Haryana	1980s	110.2	384.6	50.0	134.0	459.3	95.0	2,950.0
	1990s	117.0	339.0	16.0	175.0	585.9	98.0	3,921.0
Punjab	1980s	105.7	401.4	21.8	174.8	531.6	94.3	3,329.1
	1990s	110.8	326.2	3.8	210.2	579.7	96.4	4,066.6

Source: Compiled from the *Comprehensive Scheme for the Study of Cost of Cultivation of Principal Crops in India,* Government of India (various issues).

V

RESULTS

Following the methodology described in Section III, we have compared the Malmquist Productivity Indices for the major wheat producing states in India. Table 3 represents the average and corresponding decomposition results year-wise. In this study, we decomposed the Malmquist Productivity Index into the technical change index (TECHCH) and efficiency change (EFFCH) index. In order to identify the changes in scale efficiency, EFFCH was further decomposed into pure efficiency change (PECH) and scale efficiency change (SECH).

TABLE 3. SUMMARY OF MALMQUIST PRODUCTIVITY INDICES AND ITS DECOMPOSITION YEAR-WISE

Year (1)	EFFCH (2)	TECHCH (3)	PECH (4)	SECH (5)	TFPCH (6)
1982-83	1.034	0.792	1.028	1.006	0.819
1983-84	1.002	1.024	1	1.002	1.027
1984-85	0.988	1.021	1	0.988	1.008
1985-86	0.998	1.108	0.991	1.007	1.105
1986-87	0.997	1.041	0.999	0.997	1.037
1987-88	0.997	0.93	0.998	0.999	0.928
1988-89	0.981	1.013	0.982	0.999	0.994
1989-90	1.006	1.043	0.997	1	1.049
1990-91	1.009	1.13	1.009	0.999	1.14
1991-92	0.977	1.015	1	0.977	0.992
1992-93	1.011	1.069	0.991	1.021	1.081
1993-94	1.019	0.979	1.016	1.003	0.997
1994-95	0.98	1.245	0.979	1	1.22
1995-96	1.017	0.945	1.017	1	0.961
1996-97	1.006	1.013	1.009	0.997	1.019
1997-98	1.014	0.944	1.011	1.003	0.957
1998-99	0.995	1.124	0.995	1.001	1.118
1999-2000	0.996	1.138	0.997	0.999	1.133
Mean	1.001	1.027	1	1	1.029

The results indicate that the total factor productivity change (TFPCH) in wheat production averaged at 2.9 per cent during 1982-83 to 1999-2000 (Table 3). The decomposition of TFPCH shows the mean technical progress increased at 2.7 per cent and mean technical efficiency shows a marginal increase of 0.1 per cent during that period. This suggests that the backward states are very sluggish in catching-up with the developed ones in terms of growth. The highest growth rate, among states, has been observed in Punjab (11.4 per cent), followed by Haryana (4.6 per cent). This impressive growth was entirely due to the technical progress in these states. While Rajasthan and Uttar Pradesh recorded a respective TFPG of 1.7 per cent and 0.4 per cent, Madhya Pradesh has shown a declining trend of -3.2 per cent during the period under study. Again, if we look at the input contribution,[7] the total inputs actually declined for Punjab and Haryana (Table 4). If we look at the cost structure of cultivation, the share of machine labour in these two states were almost stagnant during the period under study at slightly more than 10 per cent, but the share of animal labour cost declined substantially from 4-8 per cent to less than one per cent. Thus the output growth in these states occurred due to a dramatic increase in TFP. However, in the less developed states, Rajasthan, Madhya Pradesh, and Uttar Pradesh, the contribution of inputs has increased inspite of listless growth in the technological progress. Therefore, the higher output growth in these states reflects their higher growth rates in the use of inputs in conformity with Kalirajan and Shand's (1997) findings for the overall agriculture sector in the eighties. However, among the two components of TFPCH, the change in technical efficiency, except for Uttar Pradesh, had remained unchanged for all other states under study. The unchanged technical efficiency in case of Punjab and Haryana is understandable as they are on the best frontier. But in case of Madhya Pradesh and Rajasthan, the stagnancy in the technical efficiency is depressing, as both of the states do not enjoy the much headway in the technical progress. In fact the technical change was negative of -3.2 per cent in case of Madhya Pradesh. For Rajasthan it was marginal increase of 1.7 per cent, which is much lower in comparison to the Punjab (11.4 per cent) and Haryana (4.6 per cent). This was also evidenced by Arnade (1998), who argued that in many developing countries, the increased technical change associated with decline in efficiency may arise from the unfamiliarity with the new technology. In case of Uttar Pradesh, the growth in technical efficiency and decline in technical change suggest that the increased TFP in the wheat production in this state arose from the improvements in technical efficiency rather than the innovation in technology.

TABLE 4. SUMMARY OF INDICES OF MALMQUIST PRODUCTIVITY, OUTPUT GROWTH AND INPUT CONTRIBUTION (1982-83 to 1999-2000)

States (1)	EFFCH (2)	TECHCH (3)	PECH (4)	SECH (5)	TFPCH (6)	Output growth (7)	Input contribution (8)
Rajasthan	1	1.017	1	1	1.017	1.027	1.0106
Madhya Pradesh	1	0.968	1	1	0.968	1.031	1.0640
Uttar Pradesh	1.007	0.997	1.005	1.002	1.004	1.021	1.0175
Haryana	1	1.046	1	1	1.046	1.030	0.9849
Punjab	1	1.114	1	1	1.114	1.020	0.9158
Mean	1.001	1.027	1	1	1.029	1.026	0.9985

Now if we divide the entire period under study into two as pre- and post-macro reform periods, i.e., 1982-83 to 1990-91 and 1991-92 to 1999-2000, respectively, we get some interesting observations (Table 5). The decomposition of TFPCH into its components suggests that the source of the productivity growth mainly was progress in technology (TECCH) rather than an efficiency increase (EFFCH). In Punjab the TFP growth has more than doubled from 7.91 per cent in the pre-reform to 18.6 per cent in the post-reform period, and in case of Madhya Pradesh it turned from a negative of -0.9 per cent to 4.2 per cent in the post-reform period. The technical

TABLE 5. SUMMARY OF DECOMPOSITION OF MALMQUIST INDICES FOR THE PERIOD 1982-1990 AND 1991-1999

States	EFFCH		TECHCH		TFPCH	
	1980s	1990s	1980s	1990s	1980s	1990s
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Rajasthan	1	1	1.042	1.018	1.042	1.018
Madhya Pradesh	1	1.002	0.919	1.039	0.919	1.042
Uttar Pradesh	1.008	1.010	1.0004	0.999	1.007	1.0004
Haryana	1	1	1.086	1.061	1.086	1.061
Punjab	1	1	1.079	1.186	1.079	1.186
Mean	1.001	1.002	1.011	1.052	1.012	1.053

progress in these States was almost the same during both periods. In case of Haryana, Uttar Pradesh, and Rajasthan the TFP growth has actually declined during the post-macro reform period in comparison to the pre-reform period. It plummeted from 8.6 per cent to 6.1 per cent (for Haryana), and 4.2 per cent to 1.8 per cent (Rajasthan). The decline in the TFP growth in these states was mainly due to dwindling technical progress in the post-reform period. For Uttar Pradesh, the decline in TFP from 0.7 per cent in the 1980s to 0.04 per cent in the 1990s was due to a negative growth in technological progress of -0.1 per cent in the 1990s. Overall, while there was practically no change in efficiency, the further decomposition of EFFCH into PECH and SECH sheds some picture. The SECH of one imply scale efficiency or CRS and SECH less than or greater than one entail inefficiency, which may be due to decreasing or increasing returns to scale. In case of Rajasthan and Uttar Pradesh the scale efficiency, SECH has improved in the 1990s. Also except for Uttar Pradesh, the high PECH has been observed in comparison to SECH in all the states under study. The low PECH in comparison to SECH in Uttar Pradesh suggests that inefficiency are mostly due to inefficient wheat production practices.

The doubling of the TFP growth in Punjab during the post-reform with unaltered technical efficiency was solely due to surge in the technical change, which resulted in the shifts in the production frontier. This may be because of its more matured and/or sustained public R&D extension whose intensity is the highest except in Kerala, supplies of new inputs including irrigation, power, and credit, besides input subsidies and private investment by the farmers. In fact Punjab has allocated the highest resources during the plan periods to infrastructure development for agriculture in terms of annual capital expenditure per hectare of net sown area, and it has increased to Rs. 618 in the Eighth plan (1992-97) from Rs. 355 in the Seventh plan (1985-90) (Chand, 2000). In case of Haryana it was only Rs. 215 during the Eighth plan. Wheat price supports may not have been so important because it was available to Haryana and other states too, and yet their TFP growth has declined in the post-reform period.[8] The increase in TFP in Madhya Pradesh was due to an increase in technical change of 3.9 per cent and technical efficiency of 0.20 per cent. The spurt in the technological progress in Madhya Pradesh during the post-reform period was due to increased use of “complementary” inputs like chemical fertilisers, machine labour, and irrigation (Table 2). The diffusion of technology during the post-reform period in Madhya Pradesh has been reflected in the share of cost of production too. Use of machine power has been taken up in a fairly significant way, with its share in the total cost increased from 2.3 per cent in 1981-82 to 9.1 per cent in 1999-2000. The increased use of machine power has restrained the increase in the cost of animal labour whose share has reduced from 19 per cent in 1981-82 to 3 per cent in 1999-2000 (Government of India, *Reports of the Commission for Agricultural Costs and Prices*, various issues).

The results obtained from this study have some important policy implications for the Indian agriculture at large, and wheat crop in particular. First, the less developed states in the wheat production, such as Uttar Pradesh, Rajasthan and Madhya Pradesh were technically efficient or very close to efficient. However, these states experienced very small growth or decline in agricultural technology during the 1982-2000 periods. This result indicates that these states have great potential to increase their wheat productivity through improving technical change. Second, among the low technology states, such as Madhya Pradesh, Uttar Pradesh and Rajasthan, Madhya Pradesh has shown an improvement in the technical progress in the post-macro reform period, turning TFP from negative to positive. But Uttar Pradesh and Rajasthan suffered a decline or very slow growth in technical change in the 1990s. This implies that technological progress is still very important to agricultural productivity growth for low technology states, which can be seen from the front-runner state Punjab. Third, this study supports the observation by Acharya (1997) and Desai and Namboodiri (1997) that the technical progress and efficiency improvement are key sources of long-term wheat growth and more attention should be paid through improving public expenditure in agricultural R&D, extension, irrigation, electricity, etc., besides inputs, banking, and marketing infrastructure and their delivery systems. Both pure technical change and pure technical efficiency can also be spread by a variety of complementary ways, including learning from others (Munshi, 2004), dissemination of information regarding technical skills and knowledge through schooling among farmers (Foster and Rosenzweig, 1996).

VI

CONCLUSIONS

This paper applied the Data Envelopment Analysis (DEA) approach to estimate the Malmquist productivity index for the wheat producing states in India during the period 1981-82 to 1999-2000. With the DEA approach, the Malmquist index can be decomposed into technical change and efficiency change. The technical change component captures shifts in the production frontier, providing a measure of innovation. The phenomenon of catching up is measured as an efficiency change component and captures the diffusion of technology. The approach uses only data on input and output quantities and does not require detailed price information. Also, no specific assumptions on the functional specification of the production frontier are needed. This decomposition allows us to identify the contribution of technical progress and improvement in the technical efficiency to productivity growth in Indian wheat production. As already stated this decomposition has important policy implications to identify the unused potential of existing technology.

The main conclusion of the study is that although technological progress has contributed mainly to the total productivity growth of wheat production for the period under study, it has been uneven among major wheat producing states. It is higher in the already developed states, like Punjab (11.4 per cent) and Haryana (4.6 per cent) in comparison to the relatively less developed states of Uttar Pradesh (0.4 per cent), Madhya Pradesh (-3.2 per cent), and Rajasthan (1.7 per cent) for the period 1981-82 to 1999-2000. The approach enables the identification of the "innovators" of India's wheat production, i.e., Punjab and Haryana that have contributed to a shift in India's overall production frontier. Again in Punjab the TFP growth has more than doubled from 7.91 per cent in the pre-reform to 18.6 per cent in the post-reform period due to surge in the technological change supported by matured and/or sustained public R&D, extension, supplies of new inputs including irrigation, power, and credit, besides input subsidies and private investment by the farmers; and in case of Madhya Pradesh it turned from a negative of -0.9 per cent to 4.2 per cent in the post-reform period which could point to a cycle of total factor productivity in Madhya Pradesh's wheat production. In the case of Haryana, Uttar Pradesh and Rajasthan the TFP growth has actually declined during the post-macro reform period in comparison to the pre-reform period. It plummeted from 8.6 per cent to 6.1 per cent (for Haryana), 0.7 per cent to 0.04 per cent (for Uttar Pradesh), and 4.2 per cent to 1.8 per cent (Rajasthan). The decline in the TFP growth in these states was mainly due to dwindling technical progress in the post-reform period. The increase or decrease in the TFP growth is mainly due to the increase or decrease in the technical change rather than due to technical efficiency. However, the low PECH in comparison to SECH in Uttar Pradesh suggests that inefficiency are mostly due to inefficient wheat production practices. For wheat production growth to sustain in the future, the Indian government might need to look more carefully into the factors that have caused such a serious decline in the technical progress. In this regard the increase of public investment in research and extension to develop new varieties of seeds, better credit delivery system in agriculture (Acharya, 1997), extension of rural infrastructure facilities such as irrigation, roads, etc., in lesser-developed regions are vital.

Received May 2004. *Revision accepted March 2005.*

NOTES

1. The interventions were built on three foundations, namely, improved package of farming technologies, a system of supply of critical modern inputs and a remunerative price and market environment for the farmers.

2. The output consists of crop production, livestock, and forestry, whereas inputs taken are: land (sown acreage and pasture areas), labour (workers in cropping sector only), machinery (includes tractors and draft animals and measured in horse power), and chemical fertilisers (gross weight of nitrogen, phosphorous and potash fertiliser).

3. For example, Cobb-Douglas form of production function may be incorrect for it assumes a CRS. Again a flexible translog production function, which underlies Törnqvist-Theil index (Caves *et al.*, 1982) allows for the VRS, and is specially suited for agriculture which is susceptible to Ricardo's Law of Diminishing Returns. However, the Translog function suffers from the degrees of freedom and multi-collinearity, besides a strong assumption made regarding the technological change as a function of time (Antle and Capalbo, 1988, p. 63).

4. Output oriented measure has been used in this study as output maximisation is primary decision variable here in the case of wheat production.

5. All the data of output and inputs are in per hectare terms.

6. The cost of cultivation data set provides only the input cost of machine labour, but it does provide the input price index. The author is thankful to the anonymous referee for the useful suggestion in this regard.

7. Since productivity growth is defined as output growth divided by the input growth, the contribution of inputs to output growth can be calculated by dividing the output growth index by the Malmquist productivity index. If it is less than one, then total inputs actually declines. Here output growth rate was estimated by regressing the log of output on time.

8. I owe this argument to the anonymous referee of the Journal.

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