Agricultural Economics Research Review
Vol. 26 (Conference Number) 2013 pp 109-118

Technical Change and Efficiency of Rice Production in India: A Malmquist Total Factor Productivity Approach

A. Suresh

National Centre for Agricultural Economics and Policy Research (NCAP), New Delhi - 110 012

Abstract

This paper has studied the trends in the total factor productivity (TFP) growth of rice in India for the period 1980-81 to 2009-10 and has decomposed the TFP growth into its constituent components, viz. change in technical progress and technical efficiency. The study has used Malmquist Productivity Index approach through data envelopment analysis to estimate the TFP. The analysis has also been carried out for two sub-periods, viz. 1980-81 to 1994-95 (period I) and 1995-96 to 2009-10 (period II) as well. For the overall period, the TFP change has been at a moderate rate of 0.2 per cent per year, with large inter-state variations. The positive TFP growth has been associated with a mean technical progress of 0.3 per cent and a deterioration of the mean technical efficiency by -0.1 per cent per year. Across the states, Andhra Pradesh, Punjab, Tamil Nadu and Uttar Pradesh have exhibited positive TFP growths during the overall period. The revival of the mean TFP to the level of 1.8 per cent per year during period II has mainly been effected by the positive technical change during this period. However, a matter of concern is the decline in technical efficiency. It is also observed that over the years the less-progressive states with respect to TFP growth during the period-I have caught up with the progressive states, mainly propelled by high rate of technical progress. The study has identified that during period-II the share of current and capital inputs in total cost of cultivation has reduced and input intensification has slowed down. The results have revealed that the recent yield stagnation in rice is not due to technology fatigue, but could be due to the sluggish input intensification. The study calls for policy initiatives for strengthening investments on research and extension for furthering the TFP growth and steps for sustainable input intensification.

Key words: TFP growth, technical change, efficiency, rice, Malmquist index

JEL Classification: O33, Q16, Q18

Introduction

The green revolution has significantly contributed to achieving self-sufficiency in foodgrains production in India, primarily through increasing the production of rice and wheat. This achievement was brought out through the faster spread of modern varieties (MVs) and inputs intensification. However, some researchers have reported that the MVs introduced during the green revolution period have quickly exhausted the yield potential in not only India but across the globe (Hayami and Kikuchi, 1999). Also, the modern cultivation practices has led to emergence of some visible symptoms of unsustainability in agriculture like nutrient imbalances, depletion of soil micro-nutrients, over-exploitation of groundwater, degradation of land, more frequent emergence of pests and diseases, and, diminishing returns to inputs (Chand *et al.*, 2011). This has created apprehensions about the ability of this approach in ensuring the future food security. In this context, a debate has emerged in policy circles — whether the slowdown of agricultural performance is due to technology fatigue or policy fatigue (Planning Commission, 2007; Narayanamoorthy, 2007). The

* Author for correspondence
Email: sureshkurup@ncap.res.in

bottomline of the debate is that given the high impact of agricultural income in eliminating rural poverty, ensuring total factor productivity (TFP) growth is critical to reduce rural poverty. In this context, the present paper has examined the TFP growth in rice cultivation in India and has discussed whether the slowdown in yield growth is due to technology fatigue or sluggishness in input intensification.

TFP Studies in in India and other Developing Countries

Many studies conducted in India and other developing countries have revealed that the TFP was showing a deteriorating trend even during the heyday of green revolution in the developing countries. For example, Kawagoe *et al.* (1985) had reported technological deterioration for the developing countries and progress for the developed countries after estimating the cross-country production functions for 22 less-developed countries and 21 developed countries. Some other studies have also reported negative productivity growth for agriculture in the developing countries since 1960s (Chaudhary, 2012). Nkamleu *et al.* (2003) have reported a deterioration of TFP growth after analysing data set for 10 Sub-Saharan African countries for the period 1972-1999. This deterioration was identified to be more on account of the regress in technical change. In contrast, Chinese agriculture has depicted a significant productivity growth since 1980s, although the growth rates varied considerably across subsectors (Li *et al.*, 2011). The productivity growth emancipated from either technical progress or efficiency gains, not from both of them simultaneously.

In an early study on the TFP in India, Kumar and Mruthyunjaya (1992) have reported growth in TFP of wheat during 1970-89 to be to the tune of 1.9 per cent in Punjab, 2.7 per cent in Haryana and Rajasthan, 2.6 per cent in Uttar Pradesh and 0.4 per cent in Madhya Pradesh. Kalirajan and Shand (1997) have noticed a declining trend in TFP growth for agriculture by the end of 1980s. Kumar and Mittal (2006) have reported a positive TFP growth for both rice and wheat during the two-decade period 1980-2000, but the TFP growth posted a reduction during the second decade compared to the first decade. In a study of various crops and states for the period 1975-2005, Chand *et al.* (2011) have observed considerable variation across crops and regions in the TFP growth. During the entire period under analysis, rice has posted a TFP growth of 0.67 per cent, while wheat has depicted a growth of 1.92 per cent.

Data and Methodology

Data

The basic input data for the estimation was collected from the reports of "Comprehensive Scheme for Cost of Cultivation of Principal Crops" carried out by the Directorate of Economics and Statistics, Ministry of Agriculture, Government of India, New Delhi. The data for the missing years were approximated by interpolations. The output variable was yield per hectare (kg/ha) reported by the Ministry of Agriculture. Six input variables were used in the analysis. They included usage of chemical nutrients (NPK, hg/ha), manure (q/ha), animal labour (pair hours/ha), human labour (human-hours/ha), and real costs of machine labour and irrigation[1]. The analysis was carried out for the overall period of 1980-81 to 2009-10, which was divided into two sub-periods; 1980-81 to 1994-95 (period I) and 1995-96 to 2009-10 (period II) corresponding broadly to pre- and post-reform periods, respectively. To avoid extreme variations, the triennial ending averages were used. The analysis was carried out by using the software DEAP 2.1 (Coelli, 1996).

Malmquist Productivity Index

The Malmquist Productivity Index (MPI) introduced by Caves *et al.* (1982) is based on distance functions. The output oriented Malmquist TFP index measures the maximum level of outputs that can be produced using a given level of input vector and the given production technology relative to the observed level of outputs (Coelli *et al.*, 2005). It measures the radial distance of the observed output vectors in the period t and t+1 relative to a reference technology. The Malmquist productivity index for the period t is represented by Equation (1):

$$M^t = \frac{D_0^t\ (x^{t+1}, y^{t+1})}{D_0^t\ (x^t, y^t)} \qquad \ldots(1)$$

which is defined as the ratio of two output distance functions with respect to reference technology at the

[1] The real cost were derived by deflating with price index for diesel and respectively.

period *t*. It is also possible to construct another productivity index by using period *t*+1's technology as the reference technology, which can be depicted as,

$$M^{t+1} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)} \qquad \ldots(2)$$

Thus, there exists an arbitrariness in the choice of the benchmark technology depending on the time period t or *t*+1. Fare *et al.* (1994) have removed this arbitrariness by specifying the MPI as the geometric mean of the two period indices, defined as:

$$M_0\ (x^{t+1}, y^{t+1}, x^t, y^t) = \left[\left(\frac{D_0^t\ (x^{t+1}, y^{t+1})}{D_0^t\ (x^t, y^t)}\right)\left(\frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}} \qquad \ldots(3)$$

where, the notations *x* and *y* are the vector of inputs and outputs, D_0 represents the distance and M_0 represents the Malmquist index. Fare *et al.* (1994) by using simple arithmetic manipulations have shown the MPI as the product of two distinct components, viz. technical change and efficiency change as indicated below:

$$M_0\ (x^{t+1}, y^{t+1}, x^t, y^t) = \left[\frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^{t+1}(x^t, y^t)}\right]\left[\left(\frac{D_0^t\ (x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_0^t\ (x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)\right]^{\frac{1}{2}} \qquad \ldots(4)$$

where,

$$\text{Efficiency change} = \frac{D_0^{t+1}(x^{t+1}, y^{t+1})}{D_0^t\ (x^t, y^t)} \qquad \ldots(5)$$

and,

Technical change =

$$\left[\left(\frac{D_0^t\ (x^{t+1}, y^{t+1})}{D_0^{t+1}(x^{t+1}, y^{t+1})}\right)\left(\frac{D_0^t\ (x^t, y^t)}{D_0^{t+1}(x^t, y^t)}\right)\right] \qquad \ldots(6)$$

The efficiency change can be further decomposed into pure efficiency change and scale efficiency change. A detailed account on the MPI can be had from Fare *et al.* (1994), Coelli *et al*. (2005), Bhushan (2005) and Chaudhary (2012). Introduction of linear programming based Data Envelopment Analysis popularised the Malmquist index of productivity measurement. DEA involves construction of piece-wise linear frontier based on the distribution of the data of the input and outs of various entities/ decision making units (DMUs) using linear programming framework. This frontier constructs a piecewise surface over the data such that the observed data lies on or below the constructed production frontier (Coelli *et al*., 2005). The efficiency measure for each DMU is calculated relative to this production frontier. Fare *et al.* (1994) identified four important advantages of using Malmquist Productivity Index compared to other approaches. They include: (1) the approach requires data on only quantity, and not prices. Information on prices are generally not available for every input and output for many countries; (2) the linear programming based approach doesn't assume an underlying production function, and therefore the stochastic properties associated with the error term; (3) no prior assumption regarding the optimising behaviour of the DMUs; and, (4) Since the approach allows for both movement towards the frontier and shift in the frontier, it is possible to decompose the TFP into its components viz technical change and efficiency change.

Results and Discussion

Trend in Rice Yield

The mean yield of rice has registered a significant improvement over the years, from about 1.2 tonnes/ha in 1980-81 to 2.2 t/ha in 2009-10, i.e. at the rate of 1.9 per cent per year at the national level (Table 1). A comparison between the two sub-periods revealed wide variations across states and over two periods of time. At the national level, the yield increased at the rate of 3.1 per cent per year during the first period and at the rate of only 1.3 per cent during the second period. The states also depicted a similar trend, with the exception of a few states like Punjab, which has broadly reflected plateauing of yield during the period II.

Trend in Total Factor Productivity

The trend in the Malmquist productivity index for the period 1980-81 to 2009-10 was estimated following the methodology outlined earlier. Figure 1 illustrates the movements of TFP, technical change and efficiency change from 1980-81 to 2009-10. It clearly depicts that

Table 1. Trend in yield of rice across selected states: 1980-81 to 2009-10

State	Yield (TE average, kg/ha)			Growth rates (% per year)		
	1980-81	1994-95	2009-10	1980-81 to 1994-95	1995-96 to 2009-10	1980-81 to 2009-10
Andhra Pradesh	1872	2562	3217	2.11	1.87	1.78
Bihar	921	1234	1319	2.86	-0.97	1.56
Karnataka	2008	2371	2539	1.14	1.09	1.37
Madhya Pradesh	586	845	912	1.87	-0.11	1.24
Odisha	918	1364	2167	3.51	3.84	2.17
Punjab	2760	3428	4017	1.33	1.62	1.05
Tamil Nadu	1958	3145	2857	4.34	-0.78	1.23
Uttar Pradesh	869	1836	2106	5.75	0.13	2.65
West Bengal	1347	2069	2551	4.34	1.73	2.69
Overall	1245	1847	2168	3.08	1.33	1.87

Data Source: Agricultural Statistics at a Glance (various issues)

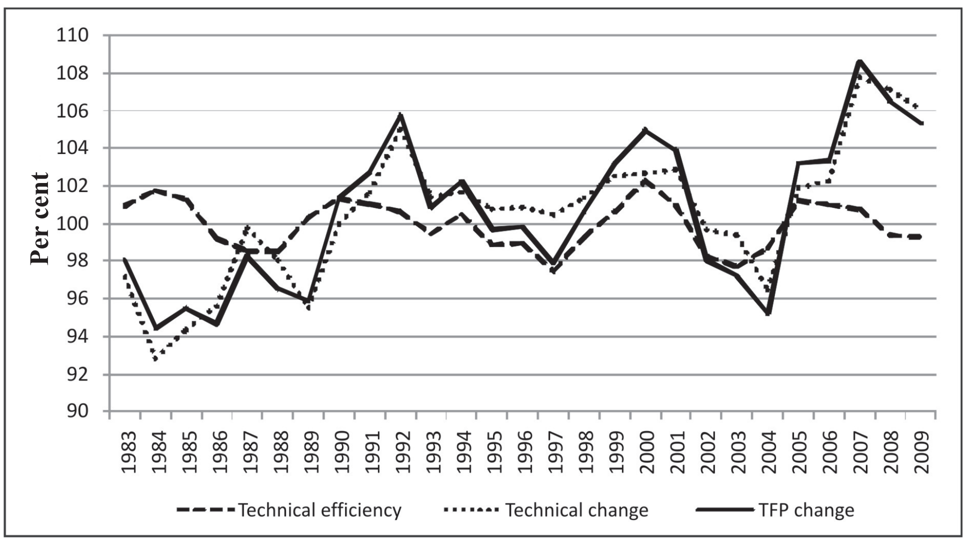

Figure 1: Movement of technical efficiency, technical change and TFP change indices of paddy cultivation: 1980-81 to 2009-2010

the movement of TFP change was aligned more with the movement of the technical progress than with the change in technical efficiency.

The results have revealed that the mean TFP change for rice has been to the tune of 0.2 per cent per year during the overall period 1980-2009 (Table 2). The decomposition analysis has indicated that the change in TFP was associated with the technical progress of 0.3 per cent and the deterioration of technical efficiency to the tune of -0.1 per cent. This underlines the fact that technical efficiency could not catch up with the technical progress, and was pulling down the TFP growth. A similar trend was noticed in case of rice in some other Asian countries as well. For example, efficiency change was not a major source of productivity growth for rice in The Philippines (Umetsu *et al.*, 2003). Within India, in case of wheat also, the major source of productivity growth was technical change than efficiency change during the period 1982-83 to 1999-2000 (Bhushan, 2005).

Table 2 also depicts the growth in TFP and its constituent components across the states for the period

Table 2. Trend in the total factor productivity and it components, across states: 1980-81 to 2009-10

State	Efficiency change	Technical change	Pure efficiency change	Scale efficiency change	TFP change
Andhra Pradesh	100.7	104.4	100.5	100.2	105.1
Bihar	100	97.7	100	100	97.7
Karnataka	99.9	98.8	100	99.9	98.7
Madhya Pradesh	98.7	96.7	100	98.7	95.4
Odisha	100	96.3	100	100	96.3
Punjab	100	104.6	100	100	104.6
Tamil Nadu	99.1	102.8	99.3	99.8	101.8
Uttar Pradesh	100.5	103.2	100	100.5	103.7
West Bengal	100	98.6	100	100	98.6
Mean	99.9	100.3	100	99.9	100.2

1980-81 to 2009-10. The TFP change varied considerably across states, with four states (Andhra Pradesh, Punjab, Tamil Nadu and Uttar Pradesh) out of the total nine states under consideration, posting positive trends and the remaining five states posting negative trends. Across states, the highest change in the TFP has been in Andhra Pradesh (5.1%), followed by Punjab (4.6%). On the other hand, the negative TFP growth ranged between -4.6 per cent in Madhya Pradesh to -1.3 per cent in Karnataka. A perusal of Table 2 reveals that the TFP change was associated more with technical change than with efficiency change at the state level also. A positive growth in both efficiency and technical change could be noted only in the case of Andhra Pradesh and Uttar Pradesh. For Punjab, a positive technical change was associated with no-change in efficiency, while for Tamil Nadu, technical change of 2.8 per cent was coupled with a efficiency change of -0.9 per cent. It is noteworthy that Karnataka and Madhya Pradesh posted decline in technical change, efficiency change and TFP during the overall period.

The change in efficiency was also decomposed into its components, viz. pure efficiency change and scale efficiency change. The pure efficiency remained unchanged at the national level and across selected states, except in Andhra Pradesh and Tamil Nadu. An increase in pure efficiency has been observed in the case of Andhra Pradesh and Uttar Pradesh. The results suggest that the agricultural development strategy has to pay increased attention towards the factors that could influence the efficiency as well along with the factors that result in technical progress.

Trend in TFP Growth during Selected Sub-periods

The sub-period-wise analysis has shown some interesting results (Table 3). It turned out that at the national level, the mean TFP growth increased from -1.3 per cent in the period I to 1.8 per cent during period II. This TFP change was associated with an improvement in the technical change (from -1.6% to 2.1%) and a decline in efficiency (from 0.3% to -0.2%). It is observed that some of the early green revolution technologies adopting states like Punjab, Tamil Nadu and Uttar Pradesh which posted high rates of TFP growth during the first period, exhibited a deterioration during the second period. On the other hand, states like Karnataka, Madhya Pradesh, Odisha and West Bengal, where TFP trend was deteriorating during period I, have shown a positive trends in period II. The results have also suggested that during the two periods, the TFP change in the latter group of states were with high level of margins, the highest absolute increase being in the case of Odisha (by 12.2 percentage points). The decline in the TFP growth of Punjab, Tamil Nadu and Uttar Pradesh was mainly due to the deterioration of technical progress rate than a decline in the efficiency growth. The revival of TFP growth in the case of Karnataka, Madhya Pradesh, Odisha and West Bengal has been due to high technological progress.

A picture of contrasting performance has been noted in Andhra Pradesh and Bihar. In Andhra Pradesh, the increasing TFP growth in the period I has increased further during period-II (from 4.0% to 7.5%), while in Bihar the deteriorating TFP growth during period-I has

Table 3. The trend in technical change, efficiency change and total factor productivity change during two periods, across selected states

State	Efficiency change		Technical change		TFP change	
	Period I	Period II	Period I	Period II	Period I	Period II
Andhra Pradesh	101.5	100.8	102.5	106.6	104.0	107.5
Bihar	100.0	100.0	99.3	95.6	99.3	95.6
Karnataka	100.0	100.3	95.3	102.1	95.3	102.4
Madhya Pradesh	99.7	98.8	91.4	101.8	91.2	100.6
Odisha	100.0	100.0	90.0	102.2	90.0	102.2
Punjab	100.0	100.0	105.6	104.0	105.6	104.0
Tamil Nadu	100.0	98.0	103.6	102.3	103.6	100.3
Uttar Pradesh	101.1	100.0	103.4	103.2	104.6	103.2
West Bengal	100.0	100.0	96.0	101.1	96.0	101.1
Mean	100.3	99.8	98.4	102.1	98.7	101.8

further deteriorated in period-II (from -0.7% to -4.4%). This contrasting performance of these two states is due to the contrasting performance of technical progress in these states. In Andhra Pradesh, the increase in the technical progress from 2.5 per cent to 6.6 per cent could surpass the deterioration of the efficiency growth, effecting a positive TFP growth. On the other hand, in Bihar, the deterioration of the technical growth from -0.7 per cent to -4.4 per cent, with efficiency remaining unchanged, pulled down the TFP growth in this state. The increase in TFP growth with practically unaltered efficiency levels points to the upward shift of the production frontier. In that sense, it can be presumed that the low-performing states during period I were trying to catch up with the already progressive states. On the other hand, results suggest that the rate of outward shift in the production frontier was slowing down in the already well-performing states, except Andhra Pradesh.

Technology Fatigue or Sluggishness in Input Intensification?

The analysis has clearly shown that TFP growth in rice has acquired greater geographical spread during recent periods. In this context, it would be worthwhile to analyse the trend in use of inputs in rice cultivation. Table 4 provides the trend in growth of application of four major inputs, viz. irrigation, fertilizer, manures and human labour. It clearly indicates that the rate of use of inputs has declined in the selected states, with a few exceptions. The decline has been sharp in use of labour, fertilizer and manure. All the selected states, except Punjab, have depicted a decline in the rate of application of fertilizers. In case of labour-use, all states, except Odisha and West Bengal, have registered negative growths. This trend has been broadly reflected in the cost of cultivation as well (Appendix I). At the national level, the cost of cultivation has increased at the rate of 9.2 per cent per year during the overall period under analysis. On disaggregated analysis, period-II has exhibited a growth rate of 7.3 per cent per year, compared to 10.9 per cent during period-I. This decline in expenditure growth (despite higher input prices during period-II) could be because of reduced rates of input application.

This trend is reflected more vividly in the change in cost structure and factor shares (Table 5). For analysis, the entire expenditure on rice cultivation was grouped into four input groups, viz. current inputs, capital inputs, labour and land[2]. Table 5 provides information on three aspects — share of inputs in total cost of cultivation (cost share), trend growth of (nominal) expenditure of these input groups, and their share in total value of output (factor share). The expenditure on the current inputs has grown at the rate of 8.0 per cent per year, on capital inputs at the rate of

[2] Current inputs were seed, fertilizer, manure, insecticides, interest on variable cost; Capital inputs were draft animal, irrigation, machinery, depreciation, interest on fixed capital; Labour input was human labour. The land revenue involved the value of land resources (both owned and hired) as well as other charges on land.

Table 4. Growth in use of irrigation (real price), fertilzer nutrients (kg/ha) and human labour (labour hours) in paddy cultivation across states, during two periods

(% per year)

State	Irrigation		Fertilizer		Labour	
	Period I	Period II	Period I	Period II	Period I	Period II
Andhra Pradesh	4.81	-13.70	2.73	1.88	-0.29	-2.29
Bihar	-7.22	23.04	7.63	1.30	-0.10	-0.74
Karnataka	9.75	-4.78	6.40	2.12	0.05	-0.28
Madhya Pradesh	19.02	1.12	8.74	-0.92	0.81	-1.99
Odisha	7.03	3.28	13.61	2.30	0.48	0.36
Punjab	1.39	-5.24	1.04	1.11	-3.25	-1.23
Tamil Nadu	5.79	-4.03	-1.36	1.85	-5.10	-2.79
Uttar Pradesh	11.30	2.74	7.99	2.76	-0.73	0.20
West Bengal	14.44	-5.09	10.23	4.11	1.20	0.42

Table 5. Trends in cost share, factor share and growth rate of various input groups in paddy cultivation at national level

Input groups	Cost share (%)			Growth rate (% per year)			Factor share (%)		
	1980-81	1994-95	2009-10	Period I	Period II	Overall	1980-81	1994-95	2009-10
Current	18.9	17.0	13.0	9.7	5.4	8.0	17.2	14.4	12.4
Capital	24.4	20.8	17.9	10.3	7.2	8.8	22.3	17.6	17.1
Labour	28.9	32.3	42.3	12.1	8.9	10.5	26.4	27.5	40.3
Land	27.8	29.9	26.8	11.1	6.2	8.7	25.4	25.4	25.6

Basic Data Source: Cost of cultivation reports of CACP

8.8 per cent, labour at the rate of 10.5 per cent and on land at the rate of 8.7 per cent for the overall period under analysis. The period II has depicted a reduction in the expenditure growth for all the input groups, most noticeably in the case of current inputs (from 9.7% to 5.4%). The expenditure on capital has reduced from 10.3 per cent to 7.2 per cent. It is a cause of concern, since the reduction in capital investment has long-term implications for farm income growth.

Corresponding to the relative growth of expenditure, the cost structure has also depicted a sharp change over time. While the expenditure shares of current input cost, capital cost and land cost in cost of cultivation have registered a decline, that of labour increased by 13 percentage points between 1980-81 to 2009-10. The spurt in the expenditure on labour has to be explained in the light of high rate of increase in agricultural wages in recent times than a physical increase in the labour absorption in rice cultivation. The results broadly suggest that it is the sluggishness in input intensification that is causing the decline in yield rather than a reduction in TFP or technical change. This indicates that the farm policies should favour sustainable intensification of inputs so as to increase the yield.

The trend in the cost share has been broadly reflected in the factor share as well. While the shares of current and capital input have declined over these years, the shares of labour and land have increased. A close observation has also revealed that technical change in rice cultivation has not made a significant percolation of benefits to the enterpreuner/ farmer in the form of increased share in the value of output during period-II.

Conclusions and Policy Implications

The study has estimated the TFP growth for rice in India and in major states and has decomposed the

TFP growth into its constituent components, viz. technical change and efficiency change. The study has also discussed whether the recent slowdown in yield growth is due to technology fatigue or sluggishness in input intensification. It is observed that during the period 1980-81 to 2009-10, the TFP growth has been at a moderate rate of 0.2 per cent per year, with large inter-state variations. The positive change in the TFP has been associated with a mean technical change of 0.3 per cent and a deterioration of mean efficiency by -0.1 per cent. The technical change has turned out to be the main driver of the TFP change.

Across states, Andhra Pradesh, Punjab, Tamil Nadu and Uttar Pradesh have exhibited positive TFP changes during the entire period under analysis. The sub-period analysis has indicated that period-II witnessed a revival of the mean TFP to the level of 1.8 per cent per year, compared to a negative TFP change of -1.3 per cent during period-I. This revival has been effected mainly by the positive technical change during the period-II. However, a matter of concern is the decline technical efficiency. It is also observed that the TFP growth has become more widespread with the passage of time. The less-progressive states with respect to TFP growth, viz. Karnataka, Madhya Pradesh, Odisha and West Bengal, in period-I have caught up with the initially progressive states during the period-II, mainly propelled by high rate of technical progress. It is also noted that the TFP growths of progressive states, except Andhra Pradesh, have deteriorated during period-II, mainly due to the regress in technical change. One state, that needs special mention is Bihar, where both the technical change and efficiency change have deteriorated over the years.

The study has brought out some important policy observations. It has established that there is no conclusive evidence for a technology regress in case of rice; rather there is evidence of technological progress over the years. However, the rate of growth of input application has been declining over the years. Therefore, rather than technological fatigue, it could be the sluggish input intensification that is contributing to the decline in yield growth of rice in the recent years. Hence, farm policies need to be aligned towards sustainable resource intensification, notably capital inputs, as they have long-term implications for farm income growth. Along with technical progress, the policies should be aligned to improve the technical efficiency of cultivation. In the light of the evidences existing on the positive role of research investment in technical progress and extension expenditure on efficiency change, the agrarian policies need to favour increased flow of resources towards the research and extension system so as to effect TFP growth through both technical and efficiency changes.

References

Bhushan, S. (2005) Total factor productivity growth of wheat in India: A Malmquist approach. *Indian Journal of Agricultural Economics*, **60**(1): 32-48.

Caves, D.W., Christensen, L.R. and Diewert, W.E. (1982) The economic theory of index numbers and the measurement of input, output and productivity, *Econometrica*, 1393-1414.

Chand, R., Kumar, P. and Kumar, S. (2011) *Total Factor Productivity and Contribution of Research Investment to Agricultural Growth in India*, Policy Paper 25. National Centre for Agricultural Economics and Policy Research, New Delhi.

Chaudhary, S. (2012) *Trend in Total Factor Productivity in Indian Agriculture: State-level Evidence using Non-parametric Sequential Malmquist Index*, Working Paper No. 215. Centre for Development Economics, Delhi School of Economics, New Delhi.

Coelli, T.J. (1996) *A Guide to DEAP Version 2.1: A Data Envelopment Analysis (Computer Program)*, Centre for Efficiency and Productivity Analysis, University of New England, Australia.

Coelli, T.J., Rao, D.S.P., O'Donnell, C.J. and Battese, G.E. (2005) *An Introduction to Efficiency and Productivity Analysis*. Springer, NewYork, USA.

Fare, R., Grosskopf, S., Norris, M. and Zhang, Z. (1994) Productivity growth, technical progress, and efficiency change in industrialised countries. *The American Economic Review,* 66-83.

Hayami, Y and Kikuchi, M. (1999) The three decades of green revolution in a Philippinevillage. *Japanese Journal of Rural Economics,***1**: 10-24.

Kalirajan, K.P. and Shand, R.T. (1997) Sources of output growth in Indian Agriculture, *Indian Journal of Agricultural Economics,* **52**(4): 693-706.

Kawagoe, T., Hayami, Y. and Ruttan, V. (1985) The inter-country agricultural production function and productivity differences among countries. *Journal of Development Economics*, **19:** 113-32.

Kumar, P. and Mittal, S. (2006) Agricultural productivity trends in India: Sustainability issues. *Agricultural Economics Research Review,* **19** (Conference No.): 71-88.

Kumar, P. and Mruthyunjaya (1992) Measurement and analysis of total factor productivity growth in wheat, *Indian Journal of Agricultural Economics*, **47** (7): 451-458.

Li, G., You, L. and Feng, Z. (2011) The sources of total factor productivity growth in Chinese agriculture: Technological progress or efficiency gain. *Journal of Chinese Economic and Business Studies*, **9**(2): 181-203.

Narayanamoorthy, A. (2007). Deceleration in agricultural growth: Technology or policy fatigue. *Economic and Political Weekly,* **42**(25): 2375-79.

Nkamleu, G.B., Gokowski, J. and Kazianga, H. (2003) Explaining the failure of agricultural production in sub-saharan Africa. *Proceedings of the 25th International Conference of Agricultural Economists*, Durban, South Africa, 16-22 August.

Otsuka, Keijiro (2000) Role of agricultural research in poverty reduction: Lesson from the Asian experience. *Food Policy,* **25**: 445-462.

Planning Commission (2007) *Report of the Steering Committee on Agriculture for Eleventh Five Year Plan (2007-2012)*, Government of India, New Delhi.

Umetsu, C., Lekprichakul, T. and Charavorty, U. (2003) Efficiency and technical change in the Philippine rice sector: A Malmquist total factor productivity analysis. *American Journal of Agricultural Economics*, **85**(4): 943-963.

Appendix 1

Trend growth in cost of cultivation and cost of production across states (nominal prices)

(% per year)

State	1980-81 to 1994-95	1995-96 to 2009-10	1980-81 to 2009-10
Andhra Pradesh	11.5	5.8	9.1
Bihar	9.7	5.3	7.9
Karnataka	10.6	5.6	9.9
Madhya Pradesh	11.4	4.6	9.3
Punjab	8.7	7.2	8.1
Tamil Nadu	10.5	4.5	6.6
Uttar Pradesh	10.9	7.2	9.1
West Bengal	11.0	10.1	10.6
Odisha	11.4	6.9	10.0
National	10.9	7.3	9.2

Basic Data Source: Cost of cultivation reports of CACP