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Trends and determinants of total factor productivity in Rice (*Oryza sativa*) and Wheat (*Triticum aestivum*)

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ABSTRACT

The study estimates total factor productivity (TFP) in rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) which form the mainstay of food security in India. The study period is 25 years from 1991–92 to 2015–16, secondary data from 12 major rice and wheat producing states was collected from Directorate of Economics and Statistics (DES). Results depict declining mean TFP for both rice and wheat in the period II (2002–2015) compared to period I (1991–2001) of study. Major producing states have been facing stagnation in productivity and the results also confirm the proposition that technical efficiency could not catch up with the technical progress in both wheat and rice cultivation. Hence, the results confirm that the TFP change was associated more with technical change than with efficiency change in all the states during both the study periods. Thus, the results conclude 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 especially in case of rice and wheat which constitute the Indian food security basket.

Keywords: Food security, Rice, Total Factor Productivity, Wheat

The growth rate of agriculture production is generally judged by the performance of rice (*Oryza sativa* L.) and wheat (*Triticum aestivum* L.) forming the staple basket. During independence, agriculture provided livelihood to about 70% of population and contributed about 48.6% of GDP (Sharma 2005). After the green revolution, Indian agriculture transformed from food shortage to self-reliant.

Total Factor Productivity (TFP) growth accounts for a higher proportion of output growth in developed countries (Pingali and Heisey 1999) than developing ones. In India, the TFP growth of rice in 1986–95 was 0.74% while in 1996–2005 it dropped to 0.40%. Similarly, in wheat it declined from 2.5% to 1.61%. But the growth rate in agriculture increased from 2.7% in 1960 to 3.4% in 2010 (Chand and Parappurathu 2012). Recent studies confirmed declining TFP in wheat in major states of Haryana and Bihar, 2000 onwards (Tripathi and Mishra 2017).

The demand for rice and wheat is expected to increase to 122 and 103 million tonnes, respectively, by 2020 assuming medium income growth (Kumar and Mittal 2006). Thus, by 2020 average yields of rice and wheat must enhance significantly. To meet the projected demand by productivity enhancement, India should have attained a per hectare yield of 2.7 tonnes for rice, 3.1 tonnes for wheat, 2.1 tonnes for maize, 1.3 tonnes for coarse cereals, 1.3 tonnes for pulses by 2020 (Agriculture Policy Vision 2020).With minimal area expansion, the growth of cereals has to be brought by enhancing total factor productivity (TFP) which is increase in output due to various technological and knowledge-based factors other than inputs like land, labor, machinery, fertilizer, seed etc. In view of the above, the present study has been conducted to estimate the TFP in rice and wheat crops from 1991–92 to 2015–16. It has also attempted to capture the sources of growth by decomposition of TFP and their contribution across the major rice and wheat growing states, and suggest policy implications to bridge the gaps in productivity.

MATERIALS AND METHODS

The study has relied on secondary data for a period of 25 years from 1991–92 to 2015–16. The input data for estimation of TFP and sources of productivity 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 state-wise analysis was carried out for the overall period of 1991–92 to 2015–16 for rice and wheat, which was divided in two sub-periods,

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viz. 1991–92 to 2001–2002 (period I) and 2002–03 to 2015–16 (period II) to depict decadal changes. 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. Seven input variables were used in the analysis. They included seeds, usage of chemical nutrients (NPK, kg/ha), manure (q/ha), animal labor (pair hours/ha), human labor (human-hours/ha), and real costs of machine labor and irrigation. WPI (Wholesale Price Index) for all commodities is used to convert the nominal input values into real values at 2011–12 base prices.

Malmquist Productivity Index (MPI) has been used for estimation of Total Factor Productivity (TFP) and it is based on distance functions (Coelli *et al.* 2005).

The Malmquist productivity index for the period t is represented by equation 1.

$$M^t = \frac{D^t_0\,(x^{t+1}, y^{t+1})}{D^t_0\,(x^t, y^t)} \qquad (1)$$

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

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

$$M_0\,(x^{t+1}, y^{t+1}, x^t, y^t) =$$

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

where, the given notations x and y are the vector of inputs and outputs, D_0 represents distance and M_0 represents the Malmquist index. Arithmetic manipulation shows MPI as the product of two distinct components, viz. technical change and efficiency change as indicated below.

$$M_0\,(x^{t+1}, y^{t+1}, x^t, y^t) =$$

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

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

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

The efficiency change is further decomposed into pure efficiency change and scale efficiency change. A detailed account on the MPI can be read from Coelli *et al.* (2005), Bhushan (2005) and Chaudhary (2012). Data Envelopment Analysis (DEA) popularized 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 output of various decision making units (DMUs) using linear programming framework.

DEA uses non-parametric envelopment frontier for the data points. Unlike Stochastic frontier, no assumptions of the functional forms of production are needed. DEA has the advantage to measure productivity growth without any price data. It helps to cope up with the agricultural prices that are highly volatile and distorted. DEA seems to be a much powerful tool for measurement of productivity and at the same time permits decomposition of TFP change into two components of efficiency change and technical change. Major drawback of DEA is that it does not account for noise

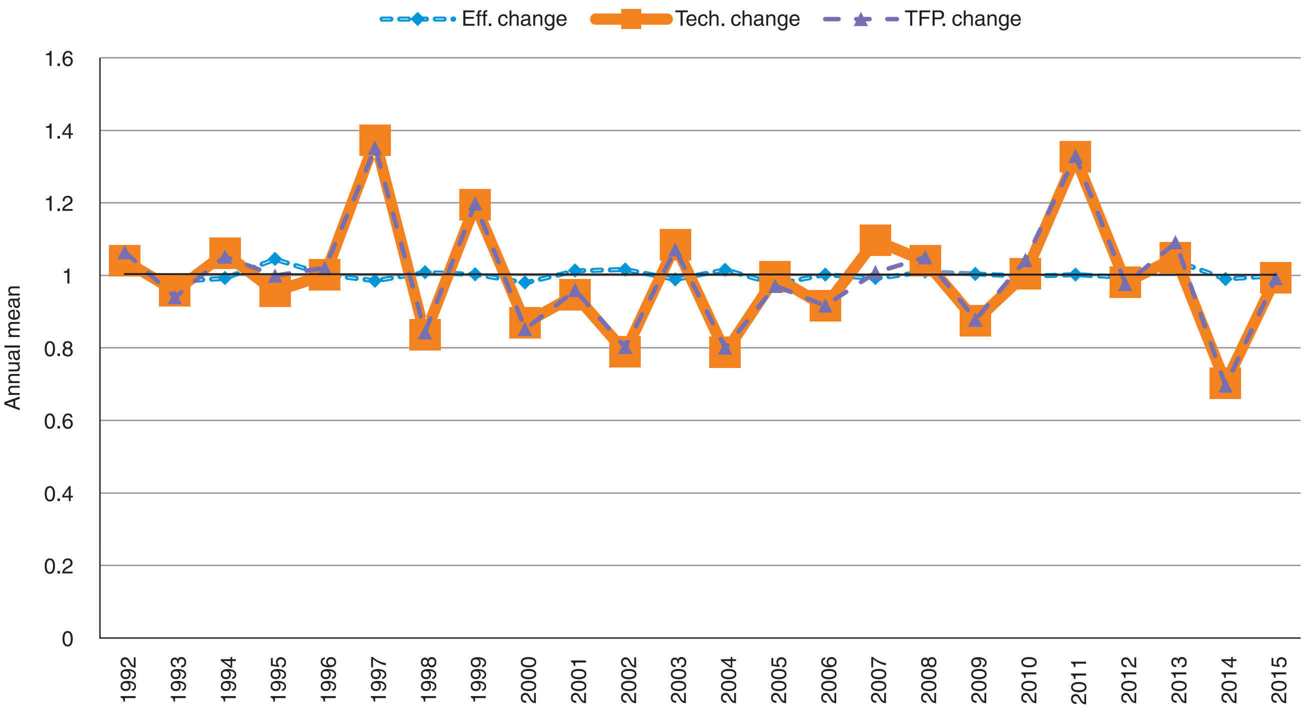

Fig 1 Annual movement of TFP indices in Rice.

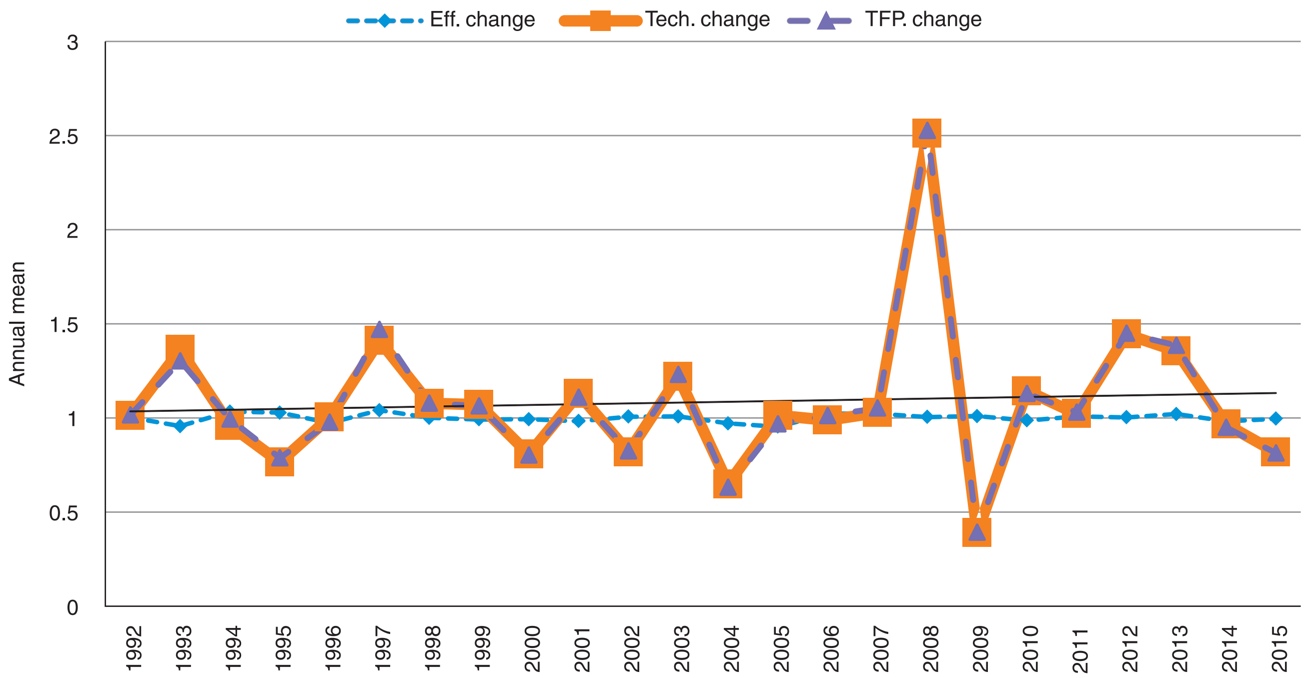

Fig 2 Annual movement of TFP indices in Wheat.

thus, conventional tests of hypotheses cannot be carried out.

RESULTS AND DISCUSSION

A rise in production can be attributed either to a growth in inputs or a growth in productivity of various inputs. The total factor productivity (TFP) reflects growth in real output that is not explained by growth in inputs. Productivity growth takes place due to movement towards the best practice referred to as changes in technical efficiency as well as changes in the best practice reflected by outward shift of production frontier termed as technical change. A rise in technical efficiency implies more output being produced with the same number of inputs or lesser inputs required to produce the same level of output (Nin *et al.* 2003). The study estimates changes in total factor productivity in major cereal producing states of India for the years 1991–92 to 2015–16 using non-parametric Malmquist TFP Index.

Mean TFP movement over time: The trend in the Malmquist productivity index for rice and wheat for the period 1991–92 to 2015–16 illustrates the annual mean total factor productivity along with efficiency and technical change. It depicts significant year to year changes in the movement of TFP in both rice and wheat, but the TFP changes are higher in wheat as compared to rice (Fig 1 and Fig 2).

It is seen that TFP change in rice and wheat has come from technical change while contribution of efficiency change is very much negligible over the period of study. Fluctuations in TFP can be attributed to technical change fluctuations rather than efficiency change. It can be analyzed by the correlated movement between the TFP changes with technical change over the time in the above plotted graphs for both rice and wheat. Higher investment in infrastructure and institutions, effective policy support from the government, availability of labor force in season are the ones that help in enhancing the efficiency of the production system by making use of quality inputs of agrochemicals and groundwater for irrigation and high yielding varieties that are the drivers which support technical change in the system (Aggarwal *et al.* 2004).

Trends in TFP and its components across rice growing states: Table 1 depicts the growth in rice TFP and its constituent components across the states in two sub periods 1991–2001 (period I) and 2002–2015 (period II). The results revealed that the mean TFP change for rice was negative for the entire period (-1.2%), though the period I showed TFP change of 1.8%, the negative TFP change (-1.9%) in period II offset the growth for entire period. This underlines the fact that total factor productivity growth had not caught up with the demands in the 2000. Rice TFP trend was positive across three states, viz. Karnataka, Punjab and Tamil Nadu for the period 1991–2015. While the remaining five states, viz. Bihar, Odisha, Uttar Pradesh, Andhra Pradesh, Madhya Pradesh and West Bengal experienced negative TFP growth trends. Across states, the highest change in the TFP is seen in Punjab (6.0%) followed by Tamil Nadu (4.9%). Only Punjab showed TFP growth greater than 5%, while Karnataka exhibited positive TFP growth in range of less than 2% per annum during the study. Though Andhra Pradesh, Karnataka and Tamil Nadu fell in medium range of TFP (2–5 %) in period I, they failed to maintain the same growth in period II as presented in Supplementary Table 1. The results are corroborated by findings of Suresh A (2013).

Trends in TFP and its components across wheat growing states: Table 2 depicts growth in wheat TFP and its constituent components across the states in two sub

Table 1 Trends in Total Factor Productivity and its sources of growth across rice growing states

State	Period I 1991–2001			Period II 2002–2015			Over all period 1991–2015		
	Efficiency change	Technical change	Total Factor Productivity change	Efficiency change	Technical change	Total Factor Productivity change	Efficiency change	Technical change	Total Factor Productivity change
Bihar	1.000	0.923	0.923	1.000	0.970	0.970	1.000	0.997	0.997
Karnataka	1.021	1.013	1.035	1.010	0.999	1.009	1.020	0.996	1.017
Odisha	1.000	0.922	0.922	1.000	0.953	0.953	1.000	0.919	0.919
Punjab	1.000	1.125	1.125	1.000	1.065	1.065	1.000	1.060	1.060
Uttar Pradesh	1.000	0.982	0.982	0.988	0.940	0.938	0.999	0.957	0.956
West Bengal	1.000	0.954	0.954	0.988	0.975	0.973	0.999	0.962	0.961
Madhya Pradesh	1.023	0.981	1.004	1.000	0.929	0.929	1.010	0.942	0.951
Andhra Pradesh	1.000	1.045	1.045	1.000	0.935	0.935	1.000	0.985	0.985
Tamil Nadu	1.000	1.036	1.036	1.000	1.069	1.069	1.000	1.049	1.049
Mean	1.005	1.013	1.018	1.001	0.980	0.981	1.003	0.985	0.988

periods 1991–2001 (period I) and 2002–2015 (period II). The mean TFP change for wheat turned out to 2.6% per annum for the entire study period. It is significant to note that wheat mean TFP declined to 2.9% in the 2000 decade from 4.4% in 1990's. This underlines the fact that total factor productivity growth has declined during the 2000 decade as against an impressive rise in TFP growth during the 1990's decade. The TFP change varied across states; Uttar Pradesh registered TFP growth of 10.8% over the period while Punjab showed 6.1%. Haryana and Rajasthan experienced slight negative growth in TFP (-0.1%) while Gujarat showed negative growth of -2.2% over the study period. All the important wheat growing states like Haryana, Madhya Pradesh, Punjab, Uttar Pradesh and Rajasthan showed an improvement in TFP growth in 2000 decade as compared to the 1990's. Across states, Uttar Pradesh and Punjab fell in the large TFP growth categories (>5%) and Madhya Pradesh alone in small TFP range (<2%) category for the entire period which is presented in Supplementary Table 2.

Categorization of states based on sources of productivity in Rice and Wheat: Decomposition analysis of TFP indices shed light on the sources of TFP growth i.e. efficiency change or technical change. These results are laid out in Supplementary Tables 3 and 4 for rice and wheat, respectively. Supplementary Table 3 depicts the growth in TFP and its constituent components across the states in rice for the period 1991–2015. Here, it's clearly seen that the change in TFP for all the positively growing states like Punjab, Tamil Nadu and Andhra Pradesh, growth had been led by technical progress rather than technical efficiency. Madhya Pradesh and Karnataka registered positive growth in efficiency; Punjab, Tamil Nadu accounted for their growth by rise in technical change with no change in efficiency. It is noteworthy that Karnataka, Madhya Pradesh with positive efficiency change experienced decline in technical change during the overall study period along with West Bengal and Uttar Pradesh, Odisha and Andhra Pradesh. A perusal of the results revealed that the TFP change was associated more with technical change than efficiency change in all

Table 2 Trends in Total Factor Productivity and its sources of growth across wheat growing states

State	Period I 1991–2001			Period II 2002–2015			Over all period 1991–2015		
	Efficiency change	Technical change	Total Factor Productivity change	Efficiency change	Technical change	Total Factor Productivity change	Efficiency change	Technical change	Total Factor Productivity change
Gujarat	1.000	1.181	1.181	0.987	0.864	0.853	0.993	0.985	0.978
Haryana	1.000	0.972	0.972	1.000	1.028	1.028	1.000	0.999	0.999
Madhya Pradesh	1.000	1.016	1.021	1.000	1.018	1.023	1.008	1.007	1.016
Punjab	1.000	1.111	1.111	1.000	1.070	1.070	1.000	1.061	1.061
Rajasthan	1.000	1.005	1.005	1.000	1.004	1.004	1.000	0.999	0.999
Uttar Pradesh	1.000	0.988	0.988	1.007	1.224	1.233	1.002	1.105	1.108
Mean	1.008	1.043	1.044	1.000	1.029	1.029	1.001	1.025	1.026

the states during both the periods. Many other studies of other Asian countries including India have shown that efficiency change was not a major source of productivity growth for rice (Suresh 2013). In states with TFP growth led by technical change, it was due to spillover effects from green revolution states along with partial irrigation facilities in states like Bihar, Tamil Nadu etc. (Janaiah *et al.* 2006).

The decomposition of TFP in wheat indicates that the change in TFP associated with the positive change in technical progress was 2.6% and the increase in technical efficiency to the tune of mere 0.1% per annum during the study period. Here too, the results confirmed that the TFP change was associated more with technical change than with efficiency change in all the states. Madhya Pradesh and Uttar Pradesh exhibited increase in technical efficiency during the entire study period, while Gujarat showed decrease in technical change as well as technical efficiency across period (Supplementary Table 4). Haryana being major wheat grower showed negative TFP growth in both periods, (-0.1%) and fell in declining category of TFP along with Rajasthan and Gujarat. All other states showed no change in efficiency in the period. Studies revealed that in India, the major source of productivity growth in wheat was technical change than efficiency change even during the period 1982–83 to 1999–2000 (Bhushan 2005). Declining TFP of wheat in Indian states along with Haryana was confirmed using Tornqvist index for the period 1990–2008 and negative growth in TFP pointed out that major source of output growth was due to growth in inputs (Tripathi and Mishra 2017).

Thus, the results suggest that the agricultural development strategy has to pay increased attention towards the factors that influence the efficiency along with the factors that result in technical progress especially in case of rice and wheat being the main stay of Indian food security program.

The study estimated the total factor productivity (TFP) in rice and wheat in major Indian states. Majority of the states in rice and wheat had shown declining TFP in second period while they registered positive growth in first period, it can be attributed to stagnation or decline in efficiency change along with slow rise of technical change. There are 'large' productivity gains occurring in Punjab in period I, while Tamil Nadu and Karnataka showed impressive gains in period II in rice. In wheat total factor productivity growth declined during the 2000s as against an impressive rise in TFP in the 1990s. Uttar Pradesh and Punjab have emerged as wheat productivity baskets leaving behind the major state Haryana.

The study revealed that in rice and wheat total factor productivity (TFP) growth occurred mainly due to technical change rather than changes in technical efficiency. It is a matter of concern as in the post green revolution period, the yield gains occurred due to intensive use of inputs has already reached the brim and the yield increases must come from efficiency changes in the long run and by spillover effects of the existing technology to nontraditional rice wheat areas.

The study suggests the following policy prescriptions like ensuring effective extension management and technology dissemination strategy. Higher priorities to crop improvement and management research, especially grown under marginal production environment and encouraging public and private investments in irrigation and infrastructure along with policy support to expand yield and agricultural production. Thus, environmentally safe strategies of production which help in maintaining the ecological balance to enhance technical change and technical efficiency are required to gain better productivity of cereals in the country.

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