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TFP Growth of Wheat and Paddy in Post-Green Revolution Era in India: Parametric and Non-Parametric Analysis§

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Abstract

This paper has applied the parametric and non-parametric approaches to estimate the Total Factor Productivity (TFP) growth for major wheat and paddy crop producing states in India for the period 1981–2010. Both the approaches have revealed that the shift due to technological adoption is a vital source for overall productivity growth. Both the approaches used have produced almost similar results at spatial and temporal directions, showing robustness in TFP estimation. Further, the high-yield states, particularly Punjab, have depicted a decline in the TFP growth for wheat and paddy crops in recent times, which raises an alarm on the long-term sustainability of paddy-wheat production system in this Green Revolution star state. An obvious extension to this study would be the application of this approach to incorporate more crops and states or at the district level. Another interesting work could be incorporating higher order policy variables such as subsidies, government investment, variables representing resource endowment, infrastructure, groundwater extraction, etc. in the efficiency equation of SFA.

Key words: TFP, Malmquist, DEA, SFA, India

JEL Classification: O13, O47, D24, Q10, Q18

Introduction

The agricultural productivity growth is most significant among the key development challenges before India's economy, especially to such concerns as food availability and rural poverty since the early-1990s. Given the binding of land constraint, agricultural growth in India depends on making land (for crops) more productive. The TFP growth in agriculture increases income for the rural communities, which promotes their spending on the non-farm sector (Ellis, 2000; Himanshu *et al.*, 2011). More specifically, it is likely to lead the rural farm communities to support non-farm commodities and services such as consumer goods and services, inputs and services to agricultural production, and processing and marketing services.

This paper has looked into the major trends and factors of change in the total factor productivity (TFP) growth of the two dominant crops, viz. wheat and paddy in the Indian agricultural landscape. Using the panel data of Indian states for the post-Green Revolution period 1981-2010, we have estimated parametric stochastic frontier analysis (SFA) (Aigner *et al.*, 1977) and non-parametric data envelopment analysis (DEA) (Charnes *et al.*, 1978), and have compared the results on the TFP measures obtained from both approaches. The rationale for using two competing approaches was to countercheck whether results obtained by one could be confirmed by the other.

By estimating input or output distance functions, non-parametric DEA can be used to decompose TFP

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growth into movements of the frontier (technical gains or innovation) and movements toward the frontier (efficiency gains or 'catching up') using the Malmquist index (see Coelli and Rao, 2005 for more details). The merit of SFA, on the other hand, is that it considers stochastic noise in data (e.g. labour or capital performance variations) and also allows for the statistical testing of hypotheses concerning production structure and degree of inefficiency. Its main limitations, however, are that it requires an explicit imposition of a particular parametric functional form representing the underlying technology and also an explicit distributional assumption for the inefficiency terms. Contextually, the parametric SFA is likely to be more appealing than the non-parametric DEA in the cases where data suffer from serious measurement errors, random events and difficulty in identifying inputs and outputs, and DEA may be better choice when random disturbances are less of an issue, and price information is not available (Färe *et al.* 1994).

Productivity Measurement in Indian Agriculture

Indian agriculture has witnessed tremendous growth during the past several decades with the adoption of Green Revolution technology during late-1960s. The sources and effects of growth have been of considerable interest to researchers, policy makers, and practitioners. With the availability of micro-level farm data, particularly of CACP, in India, few crop-specific TFP studies have been conducted since early-1990s (Sindhu and Byerlee, 1992; Kumar and Mruthyunjaya, 1992; Kumar and Rosegrant, 1994; Kumar *et al*., 1998; Kumar, 2001; Joshi *et al*., 2003). However, the India's agricultural productivity estimates lack unanimity (Table 1). This may be due to differences in the estimation methods and the data used, which has resulted into generating debates on the trend of India's agricultural productivity.

As can be seen from the Table 1, depending on the methodology and level of aggregation, the results vary substantially across studies, so careful scrutiny is required to reconcile and interpret the findings. The majority of studies have used Törnqvist Index to estimate total factor productivity (TFP) growth, with exceptions who used DEA based Malmquist Index. It is also interesting to note that the three Törnqvist approaches using FAO data from Table 1 examine the same time periods but generate widely different TFP growth estimates. Coelli and Rao's (2005) average

Table 1. A brief summary of Indian agricultural TFP studies

Study	Data sources	Sectors	Method	Period	TFP growth (%)
Rosegrant and Evenson (1992)	Indian	Crops (15)	Törnqvist	1975-1985	0.98
Evenson *et al*. (1999)	Indian	Crops (18)	Törnqvist	1977-1987	1.05
Mukherjee and Kuroda (2003)	Indian	All agriculture	Törnqvist	1973-2003	2.19
Joshi *et al*. (2003)	Indian	Rice	Törnqvist	1980-1990	3.50
				1990-1999	2.08
		Wheat		1980-1990	2.44
				1990-1999	2.14
Coelli and Rao (2005)	FAO	All agriculture	Malmquist	1980-2000	1.40
			Törnqvist	1980-2000	0.90
Bhushan (2005)	Indian	Wheat	Malmquist	1981-2000	
Kumar and Mittal (2006)	Indian	Paddy	Törnqvist	1971-2000	1.08
		Wheat			0.68
Bhushan (2009)	Indian	Wheat	Malmquist	1981-2005	1.10
Avila and Evenson (2010)	FAO	All agriculture	Törnqvist	1981-2000	2.41
Nin-Pratt *et al*. (2010)	FAO	All agriculture	Malmquist	1980-2000	0.69
Chand *et al*. (2011)	Indian	Crops & livestock	Törnqvist	1985-2006	0.53
Fuglie (2012)	FAO	All agriculture	Malmquist	1980-2000	1.39

annual Törnqvist estimate of 0.90 per cent is less than Fuglie's (2012) estimate of 1.39 per cent per annum TFP growth, which itself is significantly lower than Avila and Evenson's (2010) estimate of 2.41 per cent per annum. Coelli and Rao (2005) and Nin-Pratt *et al*. (2010) have estimated TFP using Malmquist indexes. But, their results differ, for instance, Nin-Pratt *et al*.'s estimate indicate the growth to be half of what Coelli and Rao estimate. However, as both Malmquist estimates were extracted from broader, global analyses, individual country estimates may be affected by the dimensionality issue or the number of commodities and countries (Lusigi and Thirtle, 1997). Moreover, Coelli and Rao (2005) note that if shadow prices are indeed correctly estimated, for many countries the estimates may significantly differ from the sample average due to country-specific factor abundance or scarcity. These two issues may be why the TFP growth estimates from Coelli and Rao's differ by method, their Törnqvist index indicating slower TFP growth than does their Malmquist index.

The differing years and crops included make direct comparisons of TFP growth difficult for the Indian data based studies. Recently, Ray and Ghose (2010) have used DEA approach to obtain Pareto-Koopmans measures of technical efficiency of agricultural production of states in India over the period 1970-2001. The output technical efficiency at India level averaged over all the years, was about 85.5 per cent of the Pareto optimal level. Similarly, the input-oriented technical efficiency was 0.86, implying that about 14 per cent reduction in the average level of inputs would be possible. However, the paper did not say anything about the other key component of the TFP growth, the technical progress.

A few studies have also attempted to measure TFP growth on a select group of crops or livestock products, e.g., by Fan *et al*. (1999) and Bhushan (2005; 2009). These studies have evaluated TFP growth at the state level, which is important for accounting for the entire agricultural sector and allows for a broader representation of growth. The present paper is an extension to Bhushan's (2005, 2009) studies in terms of time period, coverage of crops, and methodological expansion in estimating TFP growth of paddy and wheat in India.

Data and Methodology

Data Sources

For the estimation of TFP growth at the crop and state levels, time-series data were collected for the period 1981-82 to 2011-12 from the *Comprehensive Scheme for Studying Cost of Cultivation of Principal Crops* brought out by the CACP, Directorate of Economics and Statistics, Ministry of Agriculture, Government of India. The detailed features of CACP dataset are described in Bhushan (2015). The missing year data on inputs-use and yields per hectare were predicted using the interpolation based on the polynomial trends available in the data. The quantity data were given priority over price data, wherever both were available to avoid the anomalies in price information: Output (in kg), human labour (in hours), animal labour (pair hours), chemical inputs including fertiliser and manure (in kg) and machine labour per hectare were computed in hours. All the data were transformed by taking centered moving averages of three periods to avoid any short-term weather fluctuations, particularly rainfall effect.

Table 2 presents the data summary of the major variables used in estimating the TFP growth of wheat and paddy from 1980-81 to 2010-11. The selected five states, viz. Haryana, Madhya Pradesh, Punjab, Rajasthan and Uttar Pradesh, constituted around 80 per cent of the area and 85 per cent of the output of wheat produced in the country. Yield-wise, Punjab and Haryana are high-productive states, while Rajasthan and Uttar Pradesh fall under middle-productive states and Madhya Pradesh is in the low-producing category. One important and obvious attribute of high wheat crop yield states is higher use of material inputs like, chemical fertilisers, machine labour and intensity of irrigation in comparison to traditional inputs like human labour and animal labour. The paddy data summary also tells a similar story, except for the case of Andhra Pradesh and Karnataka, where the use of machine, human, and animal labour is substantial. Punjab and Haryana present a familiar picture of high machine combined with low human and animal labour in paddy production.

Methodological Skeleton

The sources of productivity growth of agriculture can be split into two major components (Nishimizu and Page, 1982):

Table 2. Summary of mean of inputs used per hectare in wheat and paddy crops in the selected states of India, 1981-2010s

State	Yield (kg)	Chemical fertilisers (kg)	Human labour (hours)	Machine labour@ (hours)	Animal labour (Pair hours)	Per cent irrigated area$
			Wheat			
Punjab	3,879	205	309	516	9	96.6
Haryana	3,663	170	342	485	25	97.9
Rajasthan	2,955	85	557	314	57	93.8
Uttar Pradesh	2,908	133	524	378	65	92.3
Madhya Pradesh	1,768	71	361	189	72	62.1
			Paddy			
Punjab	5,640	189	570	442	10	99.2
Andhra Pradesh	4,571	179	1,080	286	79	95.5
Karnataka	4,059	178	1,104	208	123	63.2
Haryana	3,911	175	662.5	338	13	99.4
West Bengal	3,214	82	1,192	71	160	37.5
Uttar Pradesh	3,042	100	832	170	55	58
Odisha	2,608	62	1,058	34	227	37.6
Bihar	2,149	62	863	85	127	43.0
Assam	2,191	6	686	22	256	21.8
Madhya Pradesh	1,700	49	622	51	126	18.8

Note: @For machine labour data, the cost of maintenance of farm machinery which included diesel, electricity, lubricants, depreciation, repairs and other expenses, if any, was used. The machine labour was further indexed to machine labour input price indices

$The per cent irrigated area was calculated as the ratio of total irrigated wheat (paddy) area to total wheat (paddy) sown area

(a) The efficiency gains, i.e. the growth in the factor of production, indicating the movement along the best practice production frontier, and

(b) The technological gains, i.e. shifting of the production frontier outward (inward) in case of technological progress (regress).

Based upon Farrell's (1957) original idea on technical efficiency, later studies are extended to focus on the methods of estimation of production functions (Afriat, 1972; Aigner *et al.*, 1977). The difference between actual production level of a firm and the frontier measures its technical inefficiency. The frontier can be fixed or stochastic and the estimation methodology can take a parametric or non-parametric approach. Thus, both parametric and non-parametric approaches differ in the assumptions they make regarding the shape of the efficient frontier and the existence of random error.

Non-Parametric DEA Model: Malmquist Index

Introduced by Caves *et al.* (1982) in its empirical usage, the Malmquist Index is constructed by measuring the radial distance of the observed output and input vectors in periods t and t+1 relative to two reference technologies: technology in the period t and technology in the period t+1. In this paper, we have measured TFP growth using the Malmquist index method described in Fδre *et al*. (1994) and Coelli *et al*. (2005, Ch. 11). We used the following model specified by Färe *et al.* (1994):

$$M_{OC}(x^t, y^t, x^{t+1}, y^{t+1}) = E(x^{t+1}, y^{t+1}, x^t, y^t) \times T(x^{t+1}, y^{t+1}, x^t, y^t) \quad \ldots(1)$$

where, E (.) refers to the relative efficiency change under the constant returns to scale (CRS). This measures the catching-up to the best practice frontier for each observation between two time periods t and t+1, and T(.) represents the technical change that measures the shift in the frontier of technology (or innovation) between two time periods evaluated at x^t and x^{t+1}. We have used the software DEAP (version 2.1) developed by Tim Coelli (1996 b) to estimate efficiency and productivity indices.

Parametric SFA Model: Malmquist Index

The SFA addresses technical efficiency and recognizes the fact that random shocks (as labour or capital performance) beyond the control of producers may affect the production output. These models were simultaneously introduced by Aigner *et al.*, (1977) and Meeusen and van den Broeck (1977). We have used the software FRONTIER (4.1) developed by Tim Coelli (1996 a).

In this paper, we have used translog stochastic frontier production[1] model with time-varying inefficiency in panel data as:

$$\ln Y_{it} = \beta_0 + \Sigma_j\beta_j \ln x_{ijt} + ½\Sigma_j\beta_{jj}(\ln x_{ijt})^2 + ½\,\Sigma_j\Sigma_k\beta_{jk}\ln x_{ijt} \ln x_{ikt} + \Sigma_j\beta_{jt}\ln x_{ijt}t + \beta t + ½\,\beta_{tt2} + vit - uit \quad \ldots(2)$$

where, ln denotes the natural logarithm, Y_{it} indexes the wheat and paddy productivity per hectare for the i^{th} state at time t, $x_{j\neq k}$, denotes various input variables; and β_0, β_j, β_{jj}, β_{jk}, β_{jt}, β_t, β_{tt} are the unknown parameters to be estimated. The introduction of time trend, t, interacted with input variables allows for non-neutral technical change in the model.

To account for the unobserved, non-time varying factors (or fixed effects), we included a set of input variables used in production in the specification. Due to the interest in linking the environmental sustainability and technical efficiency in production, we followed empirical development in the technical efficiency analysis literature by Kumbhakar *et al.* (1991) and Huang and Lui (1994). The technical inefficiency function, u_{it} that varies across the states can be written as:

$$u_{it} = \delta_0 + \delta_i \ln x_{it} + \omega_{it} \quad \ldots(3)$$

where, ω_{it} is the random error-term, distributed as $N(0,\sigma^2)$, x_{it}, input variables (chemical fertilisers, machine labour and irrigated area in the current model), δs are the parameters of input variables to be estimated.

The technical efficiency measures,

$$TE_{it}=E[\exp(-u_{it})|e_{it}],$$

where ($e_{it}=v_{it}-u_{it}$), can be used to calculate the efficiency change component.

Now with the help of above technical efficiency measures, the efficiency change can be estimated using following equations (Coelli *et al.*, 2005: 301):

$$\text{Efficiency change} = \frac{TE_{it}}{TE_{i(t+1)}} \quad \ldots(4)$$

$$\text{Technical change} = \exp\left\{\frac{1}{2}\left[\frac{\partial \ln Y_{i(t+1)}}{\partial(t+1)} + \frac{\partial \ln Y_{it}}{\partial t}\right]\right\} \quad \ldots(5)$$

and

$$\text{Malmquist TFP} = (\text{Efficiency Change}) \times (\text{Technical Change}) \quad \ldots(6)$$

Results and Discussion

Wheat

Before examining the parameter estimates of the production frontier and the factors that affect inefficiency of the farmers, we investigated the validity of the model used for analysis. Then we performed the joint tests using the likelihood ratio (LR) tests. The null hypotheses related to three tests of the production specifications. The results are presented in Table 3.

The first null hypothesis tests whether the Cobb-Douglas production functions is adequate to explain the underlying technology of wheat production in the selected Indian states. The second hypothesis tests whether there is no technical progress effect. The third hypothesis tests whether technical change is neutral and the fourth hypothesis tests whether technical efficiency is neutral. The test results showed that all three null hypotheses could be rejected, thus indicating that a trans-log production technology was accepted and was applicable here. The subsequent Table 4 presents the SFA estimates of translog production function used.

[1] The above specification is somewhat restrictive. It has, though, following attractive features:
- The input elasticities vary over time to capture changes in the production structure.
- The specification of technological change is general in the sense that it allows one to test whether technical change is biased towards particular inputs.
- Technical (in)efficiency is allowed to vary over time.

Table 3. Statistics for tests of hypothesis: SFA for wheat

Null hypothesis	Likelihood function	LR test statistics	Critical value at 1% level[#]	Decision
Given pooled sample	307.027			
Data can be explained by Cobb-Douglass production specification. H0: β_6=...=β_{20}=β_{22}=0	251.637	110.781	$\chi^2_{0.001,16}$ = 38.566	Reject H0
There is no technical progress effect. H0: β_{21}=β_{22}=β_{23}= β_{24}=β_{25}=β_{26}=β_{27}=0	269.346	75.362	$\chi^2_{0.001,7}$ = 23.551	Reject H0
Technical change is neutral. H0: β_{23}= β_{24}=β_{25}=β_{26}=β_{27}=0	291.825	30.404	$\chi^2_{0.001,5}$ =19.696	Reject H0
Technical efficiency is neutral. H0: δ_1= δ_2=δ_3=0	291.004	32.047	$\chi^2_{0.001,3}$ = 15.357	Reject H0

Note: [#]The correct critical values for the hypothesis involving =0 were taken from Table 1 in Kodde and Palm (1986: 1246).

To test functional forms, a likelihood ratio (LR) test was used. The translog is preferred as a more flexible functional form that allows for interaction of inputs, unlike the Cobb Douglas which does not allow for input interactions and assumes elasticity of substitution between inputs equals one (Table 3).

The variance parameters, σ^2, of the likelihood function are estimated in terms of $\sigma^2 = \sigma_u^2 + \sigma_v^2$ and $\gamma = \sigma_v^2 / \sigma^2$ is statistically significant and different from zero (Table 4).

This implies that the one-sided random inefficiency component completely dominates the measurement error and other random disturbances. The technical efficiency component, γ, indicates that the difference between actual and potential outputs is primarily due to technical and state productivity differentials in wheat productivity across state. The rejection of the null hypothesis, H0: γ=0, implies the existence of stochastic production function. The coefficient of time is 0.0585, which indicates mean technical progress of 5.8 per cent per year. However, this is statistically insignificant. The coefficient of time squared is negative and significant (at 5% level), indicating that the rate of technical change increases at a decreasing rate. Again, the efficiency response suggests that subsidy-driven input, like chemical fertiliser-use now negatively affects output growth, indicating that ironically, instead of boosting productivity, subsidies might now be contributing to lower productivity, compromising sustainability and future productivity growth.

Following the methodologies described above, Equations (1) and (6) were used to estimate TFP by DEA and SFA approaches, respectively (Table 5).

The two approaches have depicted TFP growth of 0.93 per cent (SFA) and 2.03 per cent (DEA) (Table 5). However, on excluding Punjab, the mean TFP growth of 0.84 per cent (SFA) and 0.86 per cent (DEA) were found similar for the entire modelling period, indicating robustness of the methodologies used. The dominant nature of technical change vis-à-vis efficiency change was observed for both the approaches. The technical efficiency growth had been zero or negative throughout; it indicates that as the production frontier continued to shift outwards, production kept pace, but the "yield gap" was not closed further. Similarly, in the case of input contribution to wheat output growth, except for Punjab, both DEA and SFA have shown almost similar growths, suggesting 'input intensification' in the wheat production in the Indian states.

Paddy

The SFA specification for paddy was slightly different from that of wheat, due to huge yield gap between high- and low-productive states. Further, due to different agro-climatic zones, the paddy cultivation in low-yield states, particularly in Assam and Bihar, has been regularly affected by floods. As can be seen from Table 2, Punjab has average yield more than double that of these states. Thus, dummy was used to control for these states in the panel SFA. Then we performed the joint tests using the likelihood ratio (LR)

Table 4. SFA estimation output for wheat

Variables	Parameters	Frontier function			Ordinary least squares		
		Coefficient	Standard error	t-ratio	Coefficient	Standard error	t-ratio
Constant	β_0	-42.6871	0.9850	-43.34	-42.9622	13.3357	-3.22
lnCH	β_1	1.5219	1.2074	1.26	3.7574	1.9735	1.90
lnHL	β_2	10.3612	0.7040	14.72	9.9131	2.2975	4.31
lnM	β_3	2.5596	0.9641	2.65	1.1003	1.4616	0.75
lnAL	β_4	0.9332	0.4133	2.26	1.3008	0.6238	2.09
lnIRR	β_5	1.6747	0.8600	1.95	1.8684	4.8977	0.38
lnCH^2	β_6	0.1968	0.2465	0.80	-0.0845	0.2452	-0.34
lnHL^2	β_7	-0.7100	0.2260	-3.14	-0.7445	0.4086	-1.82
lnM^2	β_8	2.5791	0.3804	6.78	2.1357	0.6982	3.06
lnAL^2	β_9	-0.0134	0.0413	-0.32	-0.0383	0.0354	-1.08
lnIRR	β_{10}	5.1192	0.6722	7.62	3.8022	1.5987	2.38
lnCH*LnL	β_{11}	0.1540	0.4511	0.34	-0.2621	0.5560	-0.47
lnCH*lnM	β_{12}	-1.3357	0.5790	-2.31	-0.9580	0.6866	-1.40
lnCH*lnAL	β_{13}	-0.2078	0.2729	-0.76	-0.4440	0.1940	-2.29
lnCH*lnIRR	β_{14}	0.6750	0.6090	1.11	0.6373	0.9573	0.67
lnHL*lnM	β_{15}	-0.3327	0.4604	-0.72	-0.1845	0.6225	-0.30
lnHL*ln AL	β_{16}	0.0585	0.1371	0.43	-0.0468	0.1734	-0.27
lnHL*lnIRR	β_{17}	-2.4483	0.6315	-3.88	-1.8415	1.7127	-1.08
lnM*lnAL	β_{18}	0.0268	0.2051	0.13	0.1161	0.1706	0.68
lnM*lnIRR	β_{19}	-5.9817	0.7438	-8.04	-4.8729	1.8156	-2.68
lnAL*lnIRR	β_{20}	-0.2981	0.2609	-1.14	-0.1232	0.4082	-0.30
T	β_{21}	0.0585	0.1371	0.43	-0.0468	0.1734	-0.27
T^2	β_{22}	-2.4483	0.6315	-3.88	-1.8415	1.7127	-1.08
lnCH*T	B_{23}	0.0268	0.2051	0.13	0.1161	0.1706	0.68
lnHL*T	B_{24}	-5.9817	0.7438	-8.04	-4.8729	1.8156	-2.68
lnM*T	β_{25}	-0.2981	0.2609	-1.14	-0.1232	0.4082	-0.30
lnAL*T	β_{26}	-0.1463	0.0676	-2.17	-0.1530	0.0846	-1.81
lnIR*T	β_{27}	-0.0007	0.0003	-2.47	-0.0009	0.0004	-2.14
Inefficiency Model							
Constant	δ_0	-1.26721	0.349403	-3.63			
lnCH	δ_0	-0.06321	0.040333	-1.57			
lnM	δ_1	-0.09271	0.099788	-0.93			
lnIRR	δ_3	0.48227	0.206038	2.34			
Variance parameters							
Sigma	σ^2	0.002242	0.00026	8.63			
Gamma	γ	1	1.25E-06	801840.6			

Note: CH=Chemical fertiliser, HL= Human labour, AL=Animal labour, M= Machine labour, IRR=Irrigation, T=Time, ln= Natural logarithm

Table 5. Sources of TFP growth for wheat, 1981-2010

State	Output growth (%)•	DEA				SFA			
		Efficiency change (%)$	Technical change (%)$	TFP change (%)$	Input contribution (%)Δ	Efficiency change (%)$	Technical change (%)$	TFP change (%)$	Input contribution (%)Δ
Haryana	1.77	0.00	1.30	1.30	0.46	-0.14	1.43	1.29	0.48
Punjab	1.26	0.00	6.90	6.90	-5.28	-0.09	1.30	1.21	0.04
Uttar Pradesh	1.43	0.10	0.80	0.90	0.53	-0.01	0.92	0.91	0.51
Rajasthan	2.01	0.00	2.30	2.30	-0.29	0.08	1.93	2.01	-0.01
Madhya Pradesh	2.75	0.00	-1.10	-1.10	3.89	-0.23	-0.52	-0.75	3.52
India	1.84	0.02	2.01	2.03	-0.18	-0.08	1.01	0.93	0.90

Notes: Growth rates are (1-index)%

$The average numbers were calculated by using geometric mean of corresponding indices estimated through DEA and SFA.

•Output trend growth of wheat yield growth was calculated by running log-linear regression on time.

ΔSince 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 (or in percentage terms negative), then total inputs actually decline.

Table 6. Statistics for tests of hypothesis: SFA for paddy

Null hypothesis	Likelihood function	LR test statistics	Critical value at 1% level#	Decision
Given pooled sample	389.029			
Data can be explained by Cobb-Douglass production specification. H0: $\beta_6=...=\beta_{20}=\beta_{22}=0$	158.299	461.458	$\chi^2_{0.001,16}=38.566$	Reject H0
There is no technical progress effect. H0: $\beta_{21}=\beta_{22}=\beta_{23}=\beta_{24}=\beta_{25}=\beta_{26}=\beta_{27}=0$	303.385	171.287	$\chi^2_{0.001,7}=23.551$	Reject H0
Technical change is neutral. H0: $\beta_{23}=\beta_{24}=\beta_{25}=\beta_{26}=\beta_{27}=0$	334.700	108.658	$\chi^2_{0.001,5}=19.696$	Reject H0
Controlling for Punjab, Assam and Bihar. H0: $\beta_{28}=\beta_{29}=\beta_{30}=0$	494.871	211.684	$\chi^2_{0.001,3}=15.357$	Reject H0
Technical efficiency is neutral. H0: $\delta_1=\delta_2=\delta_3=0$	463.464	62.814	$\chi^2_{0.001,3}=15.357$	Reject H0

Note: # The correct critical values for the hypothesis involving =0 were taken from Table 1 in Kodde and Palm (1986: 1246).

tests as done for the wheat. Using the similar battery of LR tests as discussed for wheat, we found that translog functional form was favoured over the Cobb-Douglas form (Table 6).

The inclusion of Assam and Bihar dummy was also supported by the LR test result. The summary of estimates of SFA for paddy is presented in Table 7.

The SFA results for paddy look very similar to wheat crop for variance parameters and inefficiency measure. The coefficient of time is negative and insignificant, indicating that the technical change is decreasing. The coefficients of time interacted with the chemical fertiliser are positive and with human labour, near negative, suggesting that technical change has

Table 7. SFA estimation output for paddy

Variables	Parameters	Frontier function			Ordinary least squares		
		Coefficient	Standard error	t-ratio	Coefficient	Standard error	t-ratio
Constant	β_0	-5.6640	1.1668	-4.85	-4.6706	6.0049	-0.78
lnCH	β_1	2.1228	0.8018	2.65	3.8986	0.9255	4.21
lnHL	β_2	1.3081	0.9191	1.42	0.3563	2.4046	0.15
lnM	β_3	-1.1653	0.3255	-3.58	-1.8193	0.3591	-5.07
lnAL	β_4	0.0058	0.4703	0.01	-0.0053	0.5667	-0.01
lnIRR	β_5	2.4724	1.0416	2.37	2.3731	0.8224	2.89
lnCH^2	β_6	0.1665	0.0381	4.37	0.1987	0.0447	4.45
lnHL^2	β_7	0.2758	0.3079	0.90	0.4740	0.5387	0.88
lnM^2	β_8	0.0023	0.0195	0.12	-0.0018	0.0211	-0.08
lnAL^2	β_9	0.0030	0.0393	0.08	-0.0115	0.0439	-0.26
lnIRR	β_{10}	0.6057	0.1317	4.60	0.5417	0.1529	3.54
lnCH*lnL	β_{11}	-0.4139	0.3046	-1.36	-0.8965	0.3814	-2.35
lnCH*lnM	β_{12}	-0.1958	0.0450	-4.35	-0.2178	0.0505	-4.31
lnCH*lnAL	β_{13}	-0.2170	0.1039	-2.09	-0.2269	0.1256	-1.81
lnCH*lnIRR	β_{14}	-0.1424	0.2179	-0.65	-0.2550	0.2439	-1.05
lnHL*lnM	β_{15}	0.5620	0.1505	3.74	0.7432	0.1634	4.55
lnHL*ln AL	β_{16}	-0.0681	0.2375	-0.29	-0.0528	0.2902	-0.18
lnHL*lnIRR	β_{17}	-1.4715	0.4219	-3.49	-1.3786	0.3781	-3.65
lnM*lnAL	β_{18}	-0.0702	0.0601	-1.17	-0.0908	0.0601	-1.51
lnM*lnIRR	β_{19}	-0.1245	0.0829	-1.50	-0.0433	0.0883	-0.49
lnAL*lnIRR	β_{20}	0.4152	0.1526	2.72	0.4729	0.1709	2.77
T	β_{21}	-0.0060	0.0365	-0.17	-0.0100	0.0376	-0.26
T^2	β_{22}	0.0000	0.0002	-0.01	-0.0003	0.0002	-1.69
lnCH*T	β_{23}	0.0060	0.0026	2.31	0.0024	0.0030	0.79
lnHL*T	β_{24}	-0.0092	0.0065	-1.42	-0.0062	0.0071	-0.88
lnM*T	β_{25}	0.0046	0.0014	3.38	0.0074	0.0018	4.01
lnAL*T	β_{26}	0.0042	0.0017	2.52	0.0024	0.0020	1.23
lnIR*T	β_{27}	0.0015	0.0032	0.47	0.0006	0.0047	0.13
Assam_Dum	β_{28}	0.5849	0.0743	7.88	0.7083	0.0913	7.76
Punjab_Dum	β_{29}	0.3839	0.0280	13.72	0.3649	0.0263	13.88
Bihar_Dum	β_{30}	-0.2086	0.0180	-11.60	-0.1963	0.0163	-12.07
Inefficiency Model							
Constant	δ_0	0.0543	0.0195	2.79			
lnCH	δ_0	0.0092	0.0016	5.94			
lnM	δ_1	-0.0047	0.0013	-3.60			
lnIRR	δ_3	-0.0046	0.0016	-2.89			
Variance parameters							
Sigma	σ^2	0.0044005	0.000496	8.87			
Inefficiency	Γ	1	7.61E-06	131492			

Notes: CH=Chemical fertiliser, HL= Human labour, AL=Animal labour, M= Machine labour, IRR=Irrigation, T=Time, ln= Natural logarithm

βs are the estimated parameters of the selected variables

Table 8. Sources of TFP growth for paddy, 1981-2010

State	Output growth	DEA				SFA			
		Efficiency change (%)	Technical change (%)	TFP change (%)	Input contribution (%)	Efficiency change (%)	Technical change (%)	TFP change (%)	Input contribution (%)
Andhra Pradesh	1.50	0.10	0.30	0.40	1.10	0.5	1.1	1.5	0.0
Assam	1.40	0.00	-9.60	-9.60	12.10	0.1	-1.6	-1.5	2.9
Bihar	1.20	0.10	-1.20	-1.10	2.30	-0.1	-0.1	-0.2	1.4
Haryana	1.40	0.00	1.50	1.50	-0.10	0.2	0.8	1.0	0.4
Karnataka	1.70	-1.00	-0.80	-1.80	3.60	-0.6	0.9	0.3	1.4
Madhya Pradesh	1.30	0.00	0.10	0.10	1.20	0.2	-0.2	0.0	1.2
Odisha	2.00	0.00	-4.20	-4.20	6.50	-0.4	-0.3	-0.7	1.5
Punjab	0.80	0.00	4.40	4.40	-3.40	-0.4	1.0	0.6	1.2
Uttar Pradesh	1.70	-0.10	0.00	0.00	1.70	0.1	0.4	0.5	1.1
West Bengal	1.80	0.40	-0.70	-0.30	2.10	0.0	-0.1	-0.1	1.3
India	1.50	-0.10	-1.10	-1.10	2.60	0.0	0.2	0.1	1.3

been fertiliser-using but labour-saving over this period. This indicates an outward shift of the isoquant at a faster rate over time in the fertiliser-intensive part of the input space. The TFP growth of paddy estimated using similar approach followed in wheat TFP calculation, is given in Table 8.

Unlike for wheat, the two approaches for paddy crop depicted a slightly different TFP growth — 0.1 per cent (SFA) and -1.1 per cent (DEA) (Table 8) — at mean for the entire modelling period of 1981-2010. The sources of TFP growth also differed from one another. In the case of DEA, the technical regress seemed to be the main culprit of negative TFP growth, whereas for SFA, the positive technical progress was offset by the almost no change in technical efficiency. Further, directionally, the state level TFP growth, except for Karnataka has shown an almost similar pattern under both the methods. A substantial variation of TFP growth was seen among the states.[2]

Again, a look at the input contribution revealed that the inputs-use had actually increased at the overall level for both DEA and SFA, showing 'input intensification' in paddy production output growth. This implies moving along the production surface with a given technology. This confirms the findings of Kalirajan and Shand (1997) that the output growth in agriculture is increasingly dependent on the input growth in most of the states in India. The input based growth is unsustainable in the long-run. Kumar *et al*. (2004) have also raised the concern over the indiscriminate use of natural resources in the intensively cultivated areas of the Indo-Gangetic Plains. The situation is worse in the low-yield rain-fed states, where the use of modern inputs, like machine labour and chemical inputs, is still way below the national average. This has important policy implication for the crucial need of public investment in irrigation and water management in these states, as the majority of farmers in these states are small and marginal and use input resources at sub-optimal level.

A Comparison of DEA and SFA

The temporal and spatial decomposition of TFP growth at the state level using both DEA and SFA has suggested that our results are fairly robust to the choice of methodology (Tables 9 and 10).

In comparison to previous decades, in the recent decade of 2000s, Punjab, one of the Green Revolution star states, witnessed a decline in the TFP growth for both paddy and wheat. This raises an alarm over the long run sustainability of paddy-wheat system, which brings together conflicting and complementary

[2] Barua and Das (1996) have also observed the persistence of regional inequality in India due to differences in agricultural productivity and infrastructure.

Table 9. Mean temporal and spatial DEA and SFA TFP growth for wheat

State	SFA (%)			DEA		
	1980s	1990s	2000s	1980s	1990s	2000s
Haryana	2.03	2.13	-0.03	0.80	2.28	0.63
Madhya Pradesh	-1.61	-0.24	0.21	-7.60	0.80	3.25
Punjab	1.27	1.93	0.35	7.31	10.91	2.75
Rajasthan	2.37	1.64	2.50	3.40	0.43	3.23
Uttar Pradesh	0.84	1.67	0.27	1.09	1.46	0.16
India	0.97	1.42	0.65	0.88	3.10	2.00

Table 10. Mean temporal and spatial DEA and SFA TFP growth for paddy

State	SFA			DEA		
	1980s	1990s	2000s	1980s	1990s	2000s
Andhra Pradesh	2.18	1.50	1.16	-0.98	2.92	-0.79
Assam	-2.68	-1.39	-0.51	-19.68	-4.70	-4.52
Bihar	-0.60	0.02	-0.12	-4.93	1.46	-0.20
Haryana	1.47	0.34	1.07	-1.65	-0.60	6.68
Karnataka	0.32	0.13	0.47	-4.62	-1.09	0.04
Madhya Pradesh	-2.79	0.33	1.90	-5.23	1.61	3.64
Odisha	-1.09	-1.18	-0.37	-8.67	-2.50	-1.73
Punjab	0.15	1.45	-0.27	3.72	12.59	-2.67
Uttar Pradesh	2.81	-0.67	-0.48	0.18	-0.12	-0.08
West Bengal	0.05	0.31	-0.82	0.48	-0.86	-0.49
India	-0.04	0.08	0.20	-4.35	0.78	-0.06

practices — the concern already raised by many (Murgai, 2001). The issue of sustainability of paddy productivity is fast emerging across other high-, medium- and low-yield states like Andhra Pradesh, Uttar Pradesh, West Bengal and Bihar. Much of the system operates at low yield because of inadequate nutrients and inappropriate water management (Timsina and Connor, 2001). The decline in Bihar seems to be surprising in terms of paddy production which is yet to reach its potential.[3] The decline might be due to series of floods and droughts faced by the state in the 2000s, which created a drag on the productivity in this state.

In the case of wheat producing states, only Rajasthan and Madhya Pradesh have shown a gain in TFP in the recent decade. The other three high-yield states face a decline in TFP trend in the 2000s from the previous decade. Mueller *et al*. (2012) have emphasized the crucial role of nutrients and water management in pathways towards sustainable intensification in agricultural production.

Further, the trend patterns of efficiency change, technical change and TFP change have been found to be similar for both the approaches, despite more year-to-year fluctuations in the DEA results.

The overall DEA TFP series for the Indian states is the more volatile than that of SFA. This might be due to the fact that the DEA method is more sensitive to year-to-year changes, while the stochastic frontier method appears to smoothen these effects to some degree (Bayarsaihan and Coelli, 2003). Alternatively,

[3] Banerjee (2008) has listed several possible reasons on the low level of intermediate input use, such as fertiliser, unwillingness to take risks, unavailability of credit, lack of right internal or external incentives for long-range planning, distortions in the land market or lack of understanding of the beneûts of fertiliser.

the stochastic frontier models, constrained by parameterisation, are unable to respond quickly to a sudden shift in the technology. The uneven and volatile DEA estimation of TFP in the wheat-producing states of India might be due to the sudden change in the composition of input-output combinations. Further research is required to ascertain the reasons for these anomalies. Coelli *et al*. (2005) have suggested a window method for attempting to obtain more stable DEA frontiers by pooling the data from two or three adjacent periods to construct the required frontiers.

Concluding Remarks and Way Forward

The analysis presented in this paper is the depiction of agricultural TFP growth across Indian states for two dominant crops, paddy and wheat, using non-parametric DEA and parametric SFA approach for the period1981-2010. Some important conclusions that have emerged from these findings are:

First, led by tremendous growth in the frontier states, Haryana and Punjab, technological progress has been the primary, consistent driver of productivity growth over the past three decades at India level. For wheat, the TFP growth by DEA method was 2.03 per cent and technical progress 2.01 per cent, whereas for paddy, it was -1.1 per cent for both. Part of technical regress, especially in most of the paddy producing states, could have been due to declining quality of natural resources, such as soil fertility and water mining, which warrants further investigation.

Second, technical efficiency has been plateaued throughout, with occasional improvement or decline, indicating that as the production frontier continued to shift outwards, production kept pace, but the "yield gap" was not closed further — in other words, no change in efficiency occurred. Thus, from our empirical results, we conclude that the decline and subsequent improvement in productivity in paddy and wheat production in the Indian states is most likely a result of combination of problems with management and incentive structure, as well as the absence of breakthrough in agricultural technology.

Third, the drop in TFP estimates for wheat and paddy in the recent decade for Punjab, irrespective of methodology used, reveals an alarming picture on the sustainability of paddy-wheat production system in the state. The environmental impacts causing saturation in productivity needs to be explored further with more micro-level investigations. Further, among the low-yield states, such as Rajasthan, Karnataka, and Madhya Pradesh, which have shown an improvement in the technical progress and so TFP in the later period of 2000, also suffer a technical regress in the later period. The poor technical change is most likely the result of lack of investment in technology, while low technical efficiency is generally due to management and incentive problems as well as poor information dissemination (Brooks *et al*., 1991; Foster and Rosenzweig, 1996; Acharya, 1997; Desai and Namboodiri, 1997; Munshi, 2004).

Fourth, from the methodological perspective, the technical change turned out to be a more dominant source of TFP growth, independent of choice of methodologies.

In the last, the paper does provide a quantitative understanding of agricultural production system over the recent past and in the longer-run is a useful first step toward gaining a sense of what we can expect in the years ahead.

An obvious extension to this study would be the application of this approach to incorporate more crops and states or at the district level. Another interesting work could be incorporating higher order policy variables such as subsidies, government investment, variables representing resource endowment, infrastructure, groundwater extraction, etc., in the efficiency equation of SFA. Further, our understanding of the consequences of agricultural TFP growth on the economies and environments is limited and worthy of further exploration at the micro and macro levels.

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