Technology Gap and Productivity Difference in Indian Agriculture : A Meta Frontier Analysis

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Abstract

The efficiency differentials in agriculture among different states in India was calculated by utilizing the concept of group and meta frontier production function techniques. The productivity potential of various states was calculated by utilizing the concept of Technology Gap Ratio (TGR). Empirical results were derived from a district-level input-output data set comprising of 35 major crops of 15 major Indian states covering a period of 50 years. The results showed a large technology gap ratio between the sample states of the country, ranging between 0.403 and 0.838. The study supported the view that the technology gap plays an important part in explaining the ability of agricultural sectors in one state to compete with agricultural sectors in others states in India. For calculating the efficiency results, the data envelopment analysis (DEA) was applied for the input-output data set.

Keywords: **agricultural productivity, data envelopment analysis, metafrontier function, efficiency, technology gap**

JEL Classification: N57, O47, O55, Q10

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Agriculture is customarily castigated as the Achilles' heel of the Indian economy. It is, however, rarely recognized that this sector has a lot of potential yet to be tapped just as a chained elephant. This sector has gone through ups and downs ever since the country awakened in the twilight of independence. There was a relative neglect in the sector as the documents of first two Five-Year Plans clearly demonstrate (Swamy, 2010). According to Swamy (2010), the early plan models of Mahalanobis treated this sector almost as given. However, the increasing food crisis in the early 1960s led to the adoption of the New Agricultural Policy (NEP) - popularly known as Green Revolution. This was just the beginning of a long torturous path. Essentially, NEP consists of an intensive application of the modern technology of production. It involved, with use of better HYV seeds, application of insecticides, pesticides, chemical fertilizers, and other such non organic chemical materials together with the proper doses of irrigation. In reality, however, all the conditions could not be met in balance. The imbalances are reflected in both the over utilization and underutilization of several inputs. Therefore, it is imperative to understand the pattern of input use efficiency with the adoption of NEP in Indian agriculture.

There are numerous studies concerning the technological and productive performance of agriculture in developing countries, including India (Alene, 2009 ; Bhushan, 2005 ; Coelli & Rao, 2003 ; Chand, Kumar, & Kumar, 2011 ; Fan, Hazell, & Thorat, 1998 ; Fulginiti & Perrin, 1993 ; Fulginiti & Perrin, 1998 ; Kawagoe, Hayami, & Ruttan, 1985; Kawagoe & Hayami, 1985; Kudaligama & Yanagida, 2000 ; Kumar & Mittal, 2006 ; Murgai, 1999 ; Mark & Kumar, 1994; Mukherjee & Kuroda, 2001 ; Nin, Arndt, & Preckel, 2003 ; Rao, 2005 ; Trueblood, 1996). These studies have used several yardsticks for such comparisons. Measures such as input intensities, partial productivity measures, TFP indices, efficiencies, input use parameters are the most commonly

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used. A general technique of all these procedures is to aggregate over the individual farmers to get region/state/country specific indicators. These aggregative indicators are then used to assess the performances of the farmers. Though the procedure is widely used, it suffers from some serious pitfalls. Aggregation often clouds the differences in individual responses to macro results. In agriculture, the problem is more serious because there is a huge difference across the farmer's characteristics when we consider different geographical zones of a country.

Although, in recent years, there has been a stream of research studies to appraise the efficiency of the agricultural sector in India, yet, these studies concentrated either on the efficiency of a single crop or on a single state (Kalirajan & Bhende, 2007 ; Sengupta & Kundu, 2006 ; Shanmugam, 2003; Shanmugam & Venkataramani, 2006). This study investigates productivity potentials and efficiencies of the farmers in different states in India by utilizing the concept of group and meta frontier technique. The group frontier is a representation of the state of knowledge pertaining to the transformation of inputs into output at the state level, while the meta frontier represents the state of knowledge at the country level. The ratio of the frontier score of group and the meta frontier represents the Technology Gap Ratio (TGR), which is useful to measure the productivity potential of the agricultural sector in India. Empirical results are derived from district level triennium average of input- output data set of 15 major Indian states covering a period of 50 years. For calculating the efficiency measures, the data envelopment analysis was applied for the input-output data set.

Meta Frontier and its Relation with Group Frontier

The concept of the meta production function was defined by Hayami and Ruttan (1971) : Meta production function can be regarded as the envelope of commonly conceived neoclassical production functions. The journey began with the classic article written by Førsund (1993), where he attempted to make a comparison of farms across various time points. After presenting the standard aggregative measures, he commented that it would be a waste of information to stop at presenting results for the average unit. Førsund (1993) gave an all alternative approach towards measuring aggregative efficiencies. That depends on the definition of the reference technology. The idea was elaborated to the concept of meta frontier by a number of authors (Battese & Rao, 2002 ; Battese, Rao, & O'Donnell, 2004 ; Nkamleu, Nyemeck, & Sanogo, 2006 ; O'Donnell, Rao, & Battese, 2008 ; Rao, O'Donnell, & Battese, 2003). In this paper, I have used the DEA to construct different production frontiers. This frontier surface is constructed by the solution of a sequence of linear programming problem.

DEA is a linear programming technique for constructing a non-parametric piece-wise linear envelope to a set of observed output and input data. The mathematical programming approach of DEA makes no room for 'noise' and so does not 'nearly envelop' a data set as the way most econometric models do. It is now possible to define Farrell's input saving efficiency measure based on frontier technology as [1] :

$$E_i = \min_{\alpha i}\{\alpha_i : F_i(y, \alpha_i, x) \leq 0\} \quad (1)$$

The linear programming approach to measure efficiency from the envelope is to

$$\max_{E_i, \lambda} E_i \quad (2)$$

Subject to $y_i \leq Y\lambda$

$X\lambda \leq E_i x_i$

$\lambda \geq 0$

where,

[1] Similarly, one can define output-saving efficiency measure (see Fare, Grosskopf, & Lovell, 1994).

X is a $n \times I$ input matrix with columns x_i,
Y is a $m \times I$ output matrix with columns y_i.
λ is an $I \times 1$ intensity vector

'I' is the number of farms in a particular set of observations.

Problem 2 has been solved for I time to get each producer's efficiency score, which is being evaluated under different sets of observations as envelope. Following this analysis, I calculated the efficiency scores for each of the individual districts. For example, since there are 17 districts in Andhra Pradesh, there will be about 17 different efficiency scores. I have taken the mean of these scores to be the average efficiency score belonging to this state. Regarding frontier technology, the most common restrictions are strong disposability of input and output and convexity of the set of feasible input-output combinations. One can assume three types of returns to the scale, that is, (a) constant return to scale (CRS), (b) non increasing return to scale (NIRS), (c) variable return to scale (VRS). These returns to scale assumptions impose certain restrictions on the intensity vector λ.

Under the CRS assumption, λ is unrestricted. NIRS is incorporated within a DEA structure by adding to equation 2 the constraint $e^T\lambda \leq 1$, where e is a $I \times 1$ vector of ones. Similarly, VRS might be specified by adding to equation 2 the constraint $e^T = 1$. According to Coelli (1996), the VRS specification has been the most commonly used specification in the 1990's. This study also opted for VRS specification. If we have data on L_k number of states, the above linear program is solved L_k times for each period to obtain group technical efficiency. The meta frontier is constructed using a DEA model for all the states in the country. Therefore, to obtain the technical efficiency with respect to metafrontier, we re -run the above linear program model with the input and output matrices with data for all the states together. I have used the data envelopment analysis computer programme - DEAP 2.1 - and a multi stage DEA procedure (Coelli, 1996) to run the model.

If we denote the efficiency of a state *'r'* relative to its frontier (group frontier) by TE^r_r, and the technical efficiency of the same state evaluated at the country level (meta technology) by TE^*_r, the productivity potential or technology gap ratio (TGR) of the state can be defined as (Battese et al., 2004):

$$TGR^*_r = \frac{TE^*_r}{Te^r_r} \qquad (3)$$

Thus, the technical efficiency relative to the meta frontier function is the product of the technical efficiency relative to the frontier for a given state (which is called group frontier) and the TGR. This shows that technical efficiency measured with reference to the meta technology can be decomposed into the product of the technical efficiency measured with reference to the group *'r'* technology, and the technology gap ratio between the group technology and the meta technology. As the technical efficiency relative to the meta frontier is always less than the technical efficiency relative to the group frontier, TGR is bound between zero and one.

Data Description

For empirical estimation, the present study uses district wise data on value of agricultural output and means of production of 15 major Indian states. The data set published by Bhalla and Singh (2011) in their book *Economic Liberalization and Indian Agriculture - A District Level Study* has been used. Their study takes triennium averages of input and output of 35 crops. The first triennium of 1962-65 represents the picture prevailing before the introduction of the green revolution technology. The second triennium (1970-73) represents the period that attempted to capture the initial impact of new technology in India. The third triennium (1980-83) represents further extension of new technology and its spread from the North Western region to the Southern region of India.

The triennium of 1990-93 captures the results of maturing of green revolution with preliminary effect of the newly announced economic reforms policy. The last triennium (2005-08) captures the impact of economic reforms and related changes in policy and practice on Indian agriculture.

Data regarding record of area, value of output, gross cropped area, net sown area, gross area irrigated, net area irrigated, fertilizer consumption, tractors, pump sets, and agricultural workers were obtained. For analytical purposes, the study considered value of output under 35 crops as Output and the area under 35 crops, agricultural workers, fertilizer consumption, tractors, and pump sets as Inputs. In terms of the regional coverage, the study covers 278 combined districts in 15 major states in India. The states covered are Andhra Pradesh, Assam, Bihar, Gujarat, Haryana, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, and West Bengal. The newly created states of Chhattisgarh, Jharkhand, and Uttarakhand have not been included as separated states since data for these states and their respective districts are not available prior to 1990-93. Again, Bhalla and Singh did not cover the remaining small states and union territories because of non-availability of data. To trace out any regional pattern in agricultural performance, the districts were further grouped into the following four broad regions :

- **North Western Region:** Haryana, Punjab, Uttar Pradesh
- **Eastern Region:** Assam, Bihar, Odisha, West Bengal
- **Central Region:** Gujarat, Madhya Pradesh, Rajasthan, Maharashtra
- **Southern Region:** Karnataka, Andhra Pradesh, Kerala, Tamil Nadu

Results and Discussion

Armed with the analytical tool discussed in the previous section, I now consider the empirical implication of this analysis. The mean technical efficiencies obtained from the group frontier and meta-production frontier are presented in the Table 1 for the periods under consideration.

The results of such group and meta frontier analysis for the entire time span (Table 1) shows that the technical efficiency score for the country as a whole ranged between 0.109 to 1.00, with an average of 0.512 (see the last row in Table 1). This indicates that the agricultural sector in India produces, on an average, only 51.2% of the potential output given the available technology. The more interesting feature as noted from the Table 1 is the difference between the average technical efficiency scores between the group and the meta frontier models. For example, the average technical efficiency for Bihar relative to the meta technology is only 0.380, while the average efficiency with respect to group frontier of the state is quite large, which is recorded as 0.942 (see column 8th in Table 1). Interestingly, for all the sampled states, average efficiency with respect to group frontier is higher than that with respect to meta frontier. The differences between the two efficiency scores indicates the order of bias of the technical efficiencies obtained by using the group frontiers, relative to the technology available for the agricultural sector in India as a whole (i.e., for meta frontier). Generally, the technical efficiencies from the group frontiers should be greater than those obtained from the meta production frontier, because the constraints in the group linear programming problem are a subset of the constraints in the meta-frontier linear programming problem. Considering all the periods, the results of such meta frontier analysis reveals an altered picture from group analysis (Table 1). For example, Punjab achieved second highest mean technical efficiencies relative to the group frontier, but it tended to be furthest from the potential output defined by the metafrontier function. Karnataka seems to be the least performing state in terms of mean technical efficiency with respect to group frontier, and Bihar seems to be the least performing state with respect to meta frontier.

After analyzing the data, the results encapsulated in the Table 1 reveal a number of stabilized facts. Among the zones, in general, the North Western Zone has the highest efficiency in terms of group frontier during the last 50

Table 1. Mean Technical Efficiencies Among the States Obtained from Group and Meta Frontier

State	Frontier	1962-65	1970-73	1980-83	1990-93	2005-08	All Periods	Min	Max
AP	Group	0.978	0.952	0.973	0.958	0.952	0.963	0.67	1
	Meta	0.273	0.446	0.323	0.621	0.551	0.443	0.129	1
KA	Group	0.526	0.875	0.856	0.888	0.871	0.803	0.204	1
	Meta	0.353	0.548	0.443	0.555	0.441	0.468	0.139	1
KE	Group	0.990	0.996	1.000	1.000	1.000	0.997	0.928	1
	Meta	0.549	0.915	0.715	1.000	1.000	0.836	0.207	1
TA	Group	0.966	0.979	0.873	0.915	0.852	0.917	0.478	1
	Meta	0.253	0.549	0.383	0.792	0.687	0.533	0.120	1
Southern Region	Group	0.595	0.638	0.661	0.713	0.634	0.608	0.123	1
	Meta	0.332	0.564	0.428	0.682	0.598	0.520	0.120	1
GU	Group	0.978	0.951	0.947	0.914	0.889	0.936	0.656	1
	Meta	0.272	0.485	0.365	0.477	0.503	0.420	0.167	1
MP	Group	0.942	0.910	0.766	0.898	0.912	0.886	0.261	1
	Meta	0.553	0.626	0.548	0.522	0.346	0.519	0.174	1
MH	Group	0.948	0.834	0.870	0.916	0.766	0.867	0.276	1
	Meta	0.253	0.371	0.691	0.437	0.411	0.433	0.116	1
RA	Group	0.892	0.943	0.927	0.841	0.912	0.903	0.505	1
	Meta	0.533	0.723	0.490	0.631	0.382	0.552	0.190	1
Central Region	Group	0.884	0.808	0.62	0.825	0.716	0.770	0.19	1
	Meta	0.437	0.569	0.544	0.522	0.392	0.492	0.116	1
AS	Group	0.979	0.956	0.934	0.911	0.955	0.947	0.676	1
	Meta	0.665	0.667	0.532	0.509	0.551	0.584	0.358	1
BI	Group	0.971	0.963	0.951	0.948	0.878	0.942	0.57	1
	Meta	0.308	0.451	0.374	0.475	0.291	0.380	0.119	1
OR	Group	0.989	0.978	0.970	0.974	0.952	0.973	0.812	1
	Meta	0.720	0.772	0.825	0.778	0.517	0.722	0.322	1
WB	Group	0.966	0.943	0.865	0.958	0.946	0.936	0.595	1
	Meta	0.509	0.766	0.680	0.771	0.652	0.676	0.267	1
Eastern Region	Group	0.772	0.789	0.785	0.801	0.772	0.783	0.348	1
	Meta	0.547	0.711	0.63	0.698	0.549	0.627	0.119	1
HA	Group	0.967	0.972	1.000	0.975	0.945	0.972	0.771	1
	Meta	0.313	0.666	0.375	0.655	0.522	0.506	0.214	1
PU	Group	0.982	0.967	1.000	0.983	0.940	0.974	0.767	1
	Meta	0.458	0.692	0.548	0.824	0.704	0.645	0.279	1
UP	Group	0.952	0.861	0.680	0.903	0.798	0.839	0.113	1
	Meta	0.333	0.415	0.339	0.545	0.404	0.407	0.109	1
North-Western	Group	0.942	0.881	0.711	0.907	0.793	0.846	0.113	1
	Meta	0.351	0.488	0.377	0.602	0.466	0.456	0.109	1
India		**0.415**	**0.571**	**0.496**	**0.602**	**0.477**	**0.512**	**0.109**	**1**

Notes: AP=Andhra Pradesh, AS=Assam, BI=Bihar, GU=Gujarat, HA=Haryana, KA=Karnataka, KE= Kerala, MP= Madhya Pradesh, MH= Maharashtra, OR=Odisha, PU=Punjab, RA=Rajasthan, TA=Tamil Nadu, UP=Uttar Pradesh, WB=West Bengal

Table 2. Technology Gap Ratio Estimates Among the Indian States

State	1962-65	1970-73	1980-83	1990-93	2005-08	All Periods
AP	0.279	0.468	0.332	0.649	0.579	0.460
KA	0.670	0.627	0.517	0.625	0.506	0.583
KE	0.554	0.919	0.715	1.000	1.000	0.838
TA	0.262	0.561	0.439	0.865	0.806	0.581
Southern Region	0.841	0.884	0.648	0.957	0.943	0.855
GU	0.278	0.510	0.386	0.521	0.566	0.449
MP	0.587	0.688	0.716	0.581	0.379	0.586
MH	0.267	0.445	0.794	0.478	0.537	0.499
RA	0.597	0.766	0.529	0.750	0.419	0.611
Central Region	0.494	0.704	0.877	0.633	0.547	0.639
AS	0.679	0.698	0.570	0.559	0.577	0.617
BI	0.317	0.468	0.393	0.501	0.332	0.403
OR	0.728	0.789	0.851	0.798	0.543	0.743
WB	0.527	0.812	0.786	0.805	0.689	0.722
Eastern Region	0.709	0.901	0.803	0.871	0.711	0.801
HA	0.324	0.685	0.375	0.672	0.552	0.521
PU	0.467	0.716	0.548	0.838	0.749	0.662
UP	0.350	0.482	0.499	0.603	0.507	0.486
North-Western	0.373	0.554	0.530	0.664	0.588	0.539

Notes as in Table 1.

years. Almost all literature on post-independence agrarian India considers the North Western districts of Punjab (and later Haryana) and to some extent, Western UP as the epicentre of the green revolution technology. The dominance of efficiency in this zone again confirms that the utilization pattern is the best. So far, as the triennium wise results are concerned, this zone performs much better than other zones in terms of group frontier. For example, during first triennium (i.e. in 1962-65), the average technical efficiency with respect to group frontier is 0.942, and it ranks 1st in comparison to other zones. For 2nd, 4th, & 5th trienniums, the rank is the same for this zone. However, with respect to the meta frontier approach, I cannot makes such a comment so easily. The results of such meta frontier analysis (Table 1) reveal an altered picture from group frontier analysis. The Eastern region is the best performing zone in terms of average efficiency calculated from meta frontier. Most of the districts in this zone are covered by rich alluvial soil of the Indo-Gangetic and Brahmaputra river valley. This is well suited for agricultural activities.

This study reveals the importance of meta frontier analysis at a disaggregated level. It is not justified to talk about efficiency or inefficiency of farmers in a particular state. The efficiency or inefficiency depends on the individual farmers themselves. There may be wide variation in this case except for a super performing state such as Punjab. Any policy decision made on the aggregative analysis alone would be disastrous. Some micro thinking is an essential element of any policy decision.

The group frontier is a representation of the state of knowledge/technology pertaining to the transformation of agricultural inputs into output in the region (state), while the meta frontier represents the state of the knowledge/technology at the country level. The ratio of the frontier score of the state and the meta frontier represents the technology gap ratio (TGR) of the region (or state). Now, the study estimates the technology gap ratio (TGR) as presented in the Table 2.

The Table 2 depicts that the sampled Indian states have TGR ranging between 0.403 and 0.838 during the last 50 years. These values can be interpreted as the technological gap faced by the agricultural sector in these regions when their performances are compared with the country level. Not surprisingly, Kerala has the highest productivity potential ratio (i.e. 0.838). This suggests that even if all the districts from the state achieved the best practices with respect to the technology observed in the state, they will still be lagging behind because the technology in the state lags behind the technology used at the all India level, with a technology gap ratio of 0.838. The regional level estimation of the technology gap ratio is also presented in the Table 2. The North-Western region of India, consisting of the states of Punjab, Haryana, and Uttar Pradesh, has the lowest TGR amounting to 0.539. This suggests that even if the North-Western region achieved the best practices with respect to the technology observed in the group frontier, they will still be lagging behind because their technology lags behind the all India technology level, with a technology gap ratio of 0.539.

Research Implications

This paper tries to utilize the concept of group and meta frontier technology to understand the differences in the farm level performances across the states of India. For example, a farmer in Bihar has twice constant. As an individual farmer, he cannot achieve the frontier performance of Bihar. As a farmer in Bihar, he is again unable to reach the performance level of a Punjabi farmer. Thus, his problems are two-fold - individual level that is a result of his own inefficiencies, and a group level that is a result of him being a resident of Bihar.

The findings of the present study will be accommodating in the domain of academic analysis as well as policy making. The article will be helpful to the planner and policy makers in having productivity differences among the Indian states in respect of individual as well as country level. The state level efficiency differences show the type of interventions needed to be put in place in each state for enhancing the productivity of Indian agriculture. In inefficiency studies, two types of causes, that is, man-made errors (e.g., machines failure, input indivisibility, etc.) and natural factors (e.g. abnormal rainfall, drought, etc.) are identified to explain the productivity potential of the farmers. Of these two, the influence of natural factors, particularly rainfall, is considered to be an important factor of determining productive potential of Indian farmers. However, for reducing the efficiency differences among the states, it is urgent to improve technology as well as technical know how.

Conclusion

The study investigates productivity potentials and efficiencies of the farmers in different states in India by utilizing the concept of group and meta frontier technique. The methodology enables the estimation of state wise Technology Gap Ratio (TGR) by using decomposition result involving both the group and meta frontier which examines comparative changes in the efficiency of states with respect to the meta frontier. Empirical results are derived from a triennium average of district level input output data set from 15 Indian states.

The results of this study show a large technology gap ratio between the states of India, ranging between 0.403 and 0.838. These values can be interpreted as the technological gap faced by the agricultural sector in these states when their performances are compared with the country level. The agricultural sector in the North-Eastern region has the lowest technology gap ratio, while those from the Southern states has the highest. It is also shown that although the agricultural sector at the all India level has an efficiency score of 51%, large efficiency differences exist between the states.

From a policy standpoint, the results of this study have important implications for policy making. The study clearly points out that policies need to be made to help states bring about shifts in technology. However, there exists potential to extend the current study to analyze the reasons of the wide difference in inefficiencies in agriculture in different states of India.

Limitations of the Study and Scope for Further Research

This paper has discussed the dimension of state level efficiency discourse. It has been argued that the general results emanate from the empirical application of meta frontier, which indicates a wide tapestry of relation between the productivity, efficiency, and technological attainment of the Indian state. As the present study is completely based on secondary data, limitation of the official statistics also applies. Due to unavailability of data, the study was unable to consider some of the backward states in the country. There exists potential to extend the current study to analyze reasons of the wide differences in efficiency and productivity among the different regions as well states in the country.

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