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Production Efficiency in Indian Agriculture: An Assessment of the Post Green Evolution Years

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Abstract

In this paper we use the nonparametric approach of Data Envelopment Analysis (DEA) to obtain Pareto-Koopmans measures of technical efficiency of individual states in India over the years 1970-71 through 2000-01 in a multi-output, multi-input model of agricultural production. The Pareto-Koopmans measure is a complete measure of efficiency that reflects all unrealized potential for increasing *any* output and decreasing *any* input that the firm has failed to exploit. In our empirical analysis, we disaggregate overall efficiency into two distinct components representing output and input efficiencies and identify the contributions of individual outputs and inputs to the measured level of overall efficiency. Because introduction of modern inputs has been a major component of the process of modernization of Indian agriculture, we examine to what extent different states succeeded in utilizing the modern inputs compared to the traditional inputs. Finally, we use regression analysis to explain variations in efficiency across states in terms of differences in various infra-structural, institutional, and demographic factors.

Journal of Economic Literature Classification: Q16, C61, O33

Keywords: Data Envelopment Analysis; Pareto-Koopmans Efficiency; Modern and traditional inputs.

PRODUCTION EFFICIENCY IN INDIAN AGRICULTURE:
AN ASSESSMENT OF THE POST GREEN REVOLUTION YEARS

1. Introduction

Two successive years of major crop failure in the years 1965-66 and 1966-67 resulted in severe food shortage all over the country and added urgency to India's new agricultural development strategy. Popularly known as the Green Revolution, the new agricultural policy ushered in an era of modernization in the country's traditional agriculture that had changed little from the Colonial days over the first two decades since Independence from British rule in 1947. The main pillars of the Green Revolution were introduction of high yielding varieties (HYV) of wheat and rice, widespread use of chemical fertilizers, introduction of agricultural machinery (like tractors and pump sets), extending irrigation to a greater area under cultivation thereby allowing multiple cropping, and creation of proper institutions for agricultural credit. The depth of modernization of the production technology following the Green Revolution can be judged by the increasing role of non-traditional inputs (like power, chemical fertilizers, and farm machinery) in Indian agriculture. For instance, use of chemical fertilizers increased from 2.18 million tonnes in 1970-71 to 16.7 million tonnes in 2000-01. The number of (wheel and crawler) tractors increased from 0.1 million in 1970 to 1.94 millions in 2000. Total power availability on the farm increased from 0.29 kilowatt/hectare in 1971-72 to 1.23 kilowatt/hectare in 2001-02. Area under multiple cropping increased from 25.52 million hectares in 1970-71 to 43.97 million hectares in 2001-02. There was a concomitant increase in productivity. The index of yield per acre (base: triennium ending 1981-82 = 100) increased from 93.2 in 1970-71 to 152.8 in 2000-01 for foodgrains. Corresponding change for other crops (non-foodgrain) was from 91.4 in 1970-71 to 133.2 in 2000-01. Success of the Green Revolution is evident from the fact that although deprivation and malnutrition remains an endemic problem in rural areas, India has achieved self-sufficiency in food and is no longer dependent on imports or outright aid from donor countries to feed its population. In a parallel manner, development of the non-food segment of the agricultural sector helps to foster growth of textiles, food processing, and other agro-based manufacturing. Overall, the extent of transformation of Indian agriculture over the first three decades following the Green Revolution is genuinely impressive. One cannot, however, ignore some disturbing signs that the engine of growth driving Indian agriculture is losing its steam. The index of food grains production in 2002-03 fell by 18.6% from the level reached in the previous year. This was preceded by a 6.66% drop in 2000-01 and followed by a 7.04% drop in 2004-05.

Every revolution eventually loses momentum and the system waits for another major breakthrough to sustain the growth process. This may, indeed, be the reality for Indian agriculture at this point in time. It is, nevertheless, important to investigate whether greater productivity is achievable within the limits of the prevalent technology through elimination of technical inefficiencies.

A firm is said to be weakly efficient if it is not possible to increase *all of its outputs* without increasing any input or to reduce *all of its inputs* without reducing any output. Such weak efficiency does not preclude potential for increasing some outputs or reducing some inputs (although not all). Obviously weak efficiency does not ensure Pareto efficiency. Although useful for a summary evaluation of performance, the measured level of weak efficiency (whether input- or output-oriented) fails to provide a proper benchmark for improvement. In order to become fully efficient a firm has to eliminate underproduction of every output and at the same time avoid under utilization of every input. Apart from providing a target input-output bundle that the firm should try to attain, Pareto-Koopmans analysis provides input- and output-specific measures of efficiency.

There are numerous studies in the existing literature that measure efficiency in Indian agriculture in the recent period. Kalirajan (1981) estimated a profit function using data on HYV IR 20 rice production in the *rabi* (winter) season for the year 1977-78, from a progressive village in Coimbatore district in the Indian state of Tamil Nadu and, following Lau and Yotopolus(1971), compared the relative efficiency of small and large farms. Kumbhakar and Bhattacharya (1992) estimated a generalized profit function incorporating price distortions resulting from imperfect market conditions, socio-political and institutional constraints alongside technical and allocative inefficiencies using farm level data collected by Agro-Economic Research Centre (an organization for agricultural research under the Ministry of Agriculture, Government of India) from the three regions of the Indian State of West Bengal, for the year 1980-85. Bhattacharya et al (1996) used farm level data for 105 jute growers from West Bengal to estimate a generalized indirect production function. Tadesse and Krishnamoorthy (1997) used a stochastic frontier production function and estimated technical efficiency across seven distinct agro-climatic zone and farm size groups of paddy farms of Southern Indian State of Tamil Nadu for the year 1992-93. Sengupta (2000) used 1989-90 farm level cost of cultivation data collected by Ministry of Agriculture, Government of India, to obtain alternative measures of efficiency using a non-frontier approach. Shanmugam (2002) estimated technical efficiency of rice production in different regions of Karnataka, India from 1991-92 to 1994-95, employing the stochastic frontier approach. Mythili and Shanmugam (2000), on the other hand, employed stochastic frontier methodology using panel data for the year 1990-91, 1991-92 and 1992-93 to estimate technical efficiency for the six agro-climatic zones in the state Tamil Nadu, India.

In this paper we use the nonparametric approach of Data Envelopment Analysis (DEA) to obtain Pareto-Koopmans measures of technical efficiency of individual states in India over the years 1970-71 through 2000-01 in a multi-output, multi-input model of agricultural production. Our paper extends the extant literature on measurement of efficiency in Indian agriculture in several ways. First, although there are some applications in other areas[1], to the best of our knowledge, this is the first study measuring Pareto-Koopmans efficiency in agricultural production. Pareto-Koopmans efficiency is a complete measure in the sense that it reflects unrealized potential for increasing any output and decreasing any input that the firm has failed to exploit. In our empirical analysis, we disaggregate the overall efficiency measure into two distinct components representing output and input efficiencies. Further, we are able to identify the contributions of individual outputs and inputs to the measured level of overall efficiency. Second, unlike the previous studies cited above, we examine the entire agricultural sector of the country rather than a sample of individual firms from a specific region. Moreover, we utilize a panel data set covering three decades following the Green Revolution. This enables us to track how different regions of the country have performed over this period. Because introduction of modern inputs has been a major component of the process of modernization of Indian agriculture, we examine to what extent states succeeded in utilizing the modern inputs compared to the traditional inputs. Finally, we use regression analysis to explain variations in efficiency across states in terms of difference in various infra-structural, institutional, and demographic factors. Specifically, we address the following questions:

- How do measured levels of technical efficiency as well as individual components vary across the different geographical regions (and across states within these regions)?
- Are there differences in efficiency in the utilization of traditional and non- traditional inputs?
- How do input and output-oriented efficiencies and their individual components compare across years within the sample period?

[1] Ray and Jeon (2008) measured the Pareto-Koopmans efficiency of America's top-rated MBA programs.

- What are the possible determinants of inter-state variation in efficiencies?

The rest of the paper is organized as follows. Section 2 provides an overview of the nonparametric methodology. Section 3 describes the data and reports the empirical findings from the efficiency analysis. A statistical analysis of the factors explaining the observed variation in technical efficiency is presented in section 4. The main conclusions and policy implications are summarized in section 5.

2. The Nonparametric Methodology

2.1 The Technology and Technical Efficiency

Consider an industry producing bundles of *m* outputs *y* from bundles of *n* inputs *x*. The production technology is defined by the production possibility set

$$T = \{(x, y): y \in R_+^m \text{ can be produced from } x \in R_+^n\}, \qquad (1)$$

An input-output bundle (x^0, y^0) is feasible if $(x^0, y^0) \in T$.

The bundle (x^0, y^0) is *weakly efficient* in its *input-orientation* if it is not possible to reduce all inputs simultaneously without reducing any output. That is,

$$(x^0, y^0) \in T \text{ and } \beta < 1 \Rightarrow (\beta x^0, y^0) \notin T. \qquad (2a)$$

Similarly, (x^0, y^0) is *weakly efficient* in its *output-orientation* if

$$(x^0, y^0) \in T \text{ and } \alpha > 1 \Rightarrow (x^0, \alpha y^0) \notin T. \qquad (2b)$$

That is all outputs cannot be increased simultaneously without increasing any input.

Note that input-oriented weak efficiency does not preclude reduction in one or more (though not all) inputs. Similarly, output-oriented weak efficiency is compatible with increase in one or more individual outputs. Thus, weak efficiency does not imply Pareto efficiency. Both input- and output-oriented weak efficiencies are essentially *radial* in nature because one considers radial contraction of the input bundle or a radial expansion of the output bundle.

By contrast, (x^0, y^0) is *strongly* input-efficient only if a reduction in *any* component of the x^0 input bundle would render the output bundle y^0 infeasible. That is

$$(x^0, y^0) \in T \text{ and } x \leq x^0 \Rightarrow (x, y^0) \notin T. \qquad (3a)$$

In an analogous manner, (x^0, y^0) is *strongly* input-efficient only if

$$(x^0, y^0) \in T \text{ and } y \geq y^0 \Rightarrow (x^0, y) \notin T. \qquad (3b)$$

Finally, $(x^0, y^0) \in T$ is Pareto-Koopmans efficient if both of the following conditions simultaneously hold

(i) $x \leq x^0 \Rightarrow (x, y^0) \notin T;$ (4a) and

(ii) $y \geq y^0 \Rightarrow (x^0, y) \notin T.$ (4b)

Thus, strong input- and output-efficiency are both necessary and are together sufficient for Pareto-Koopmans efficiency.

2.2 Data Envelopment Analysis

In order to calibrate any of the various technical efficiency measures considered above, we need to construct the production possibility set empirically from observed data. In parametric models, one starts with an explicit specification of the production technology in the form of a production function (in the single output case) or a transformation function (in the multiple output case) and uses appropriate statistical methods to obtain estimates of the parameters of the specified function from sample data. By contrast, in the nonparametric approach of Data Envelopment Analysis (DEA) one makes a number of fairly general assumptions about the underlying technology but specifies no explicit functional form. Introduced by Charnes, Cooper, and Rhodes (CCR) (1978) and further generalized by Banker, Charnes, and Cooper (BCC) (1984), DEA allows one to construct the production possibility set empirically from observed data. Specifically, one makes the following assumptions:

(i) Each input-output bundle (x^j, y^j) $(j = 1,2,\ldots,N)$ actually observed in the sample is feasible.

(ii) The production possibility set T is convex.

(iii) Inputs are strongly disposable. That is, if $(x^0, y^0) \in T$ and $x^1 \geq x^0$, then $(x^1, y^0) \in T$.

(iv) Outputs are freely disposable. That is, if $(x^0, y^0) \in T$ and $y^1 \leq y^0$, then $(x^0, y^1) \in T$.

(v) If constant returns to scale hold, if $(x^0, y^0) \in T$, then $(kx^0, ky^0) \in T$ for all $k \geq 0$.

It can be easily verified that the free disposal convex hull of the observed input-output data

$$S^V = \left\{(x,y) : x \geq \sum_1^N \lambda_j x^j ; y \leq \sum_1^N \lambda_j y^j ; \sum_1^N \lambda_j = 1; \lambda_j \geq 0 \ (j = 1,2,...,N)\right\} \qquad (5a)$$

is the smallest set satisfying assumptions (i)-(iv). The corresponding production possibility set satisfying the CRS assumption is

$$S^C = \left\{(x,y) : x \geq \sum_1^N \lambda_j x^j ; y \leq \sum_1^N \lambda_j y^j ; \lambda_j \geq 0; (j = 1,2,....,N)\right\} \qquad (5b)$$

Radial Measures of Technical Efficiency

Following Banker, Charnes, and Cooper (1984), the input-oriented radial technical efficiency of a firm with an observed input-output bundle *(x^0, y^0)* under the variable returns to scale assumption is obtained as:

$$\tau_x(x^0, y^0) = \min \theta$$

$$\text{s.t. } \sum_1^N \lambda_j y^j \geq y^0;$$

$$\sum_1^N \lambda_j x^j \leq \theta x^0; \qquad (6)$$

$$\sum_1^N \lambda_j = 1;$$

$$\lambda_j \geq 0; \ (j = 1,2,..., N)$$

Similarly, the output-oriented radial technical efficiency under VRS is measured as

$$\tau_y(x^0, y^0) = \tfrac{1}{\varphi^*}$$

where $\varphi^* = \max \varphi$

$$\text{s.t. } \sum_1^N \lambda_j y^j \geq \varphi y^0;$$

$$\sum_1^N \lambda_j x^j \leq x^0; \qquad (7)$$

$$\sum_1^N \lambda_j = 1;$$

$$\lambda_j \geq 0; \ (j = 1,2,..., N)$$

When CRS is assumed, the restriction $\sum_1^N \lambda_j = 1$ is deleted from (6) or (7). It is obvious that neither the input- nor the output-oriented radial measure of technical efficiency is affected by the presence (or magnitude) of slacks in any of the individual input or output constraints in (6) or (7).

Non-Radial Measures of Technical Efficiency

The problem of slacks in any optimal solution of a radial DEA model arises because we seek to expand all outputs or contract all inputs by the same proportion. In non-radial models, one allows the individual outputs to increase or the inputs to decrease at different rates. Färe and Lovell (1978) introduced the following input-oriented, *non-radial* measure of technical efficiency called the Russell measure:

$$\rho_x(x^0, y^0) = \min \tfrac{1}{n} \sum_i \theta_i$$

$$\text{s.t.} \quad \sum_j \lambda_j y_{rj} \geq y_{r0}; \ (r = 1,2,\ldots,m);$$

$$\sum_j \lambda_j x_{ij} \leq \theta_i x_{i0}; \ \ (i= 1, 2,\ldots, n); \qquad (8)$$

$$\sum_j \lambda_j = 1; \ \ \lambda_j \geq 0; \ (j =1, 2,\ldots, N).$$

When input slacks do exist at the optimal solution of a radial DEA model, the non-radial Russell measure in (8) falls below the conventional measure obtained from an input-oriented BCC model (6). Because the radial projection is always a feasible solution for (8), $\rho_x \leq \tau_x$. That is, the non-radial Russell measure of technical efficiency never exceeds the corresponding radial measure.

The analogous output-oriented non-radial VRS measure of technical efficiency is:

$$RM_y(x^0, y^0) = \frac{1}{\rho_y},$$

where $$\rho_y = \max \tfrac{1}{m} \sum_r \phi_r$$

$$\text{s.t.} \quad \sum_j \lambda_j y_{rj} \geq \phi_r y_{r0}; \ (r = 1,2,\ldots,m);$$

$$\sum_j \lambda_j x_{ij} \leq x_{i0}; \ \ (I = 1, 2,\ldots, n); \qquad (9)$$

$$\sum_j \lambda_j = 1; \ \ \lambda_j \geq 0; \ (j =1, 2,\ldots, N).$$

While no input slacks can exist at the optimal solution of (8), presence of any output slack is not ruled out. Similarly, input slacks may remain at the optimal solution of (9). Thus, non-radial technical efficiency (whether input-oriented or output-oriented) by itself does not ensure over all Pareto efficiency.

A non-radial Pareto-Koopmans measure of technical efficiency of the input-output pair *(x^0, y^0)* can be computed as:

$$\gamma(x^0, y^0) = \min \frac{\frac{1}{n}\sum_i \theta_i}{\frac{1}{m}\sum_r \phi_r}$$

$$\text{s.t.} \quad \sum_{j=1}^{N} \lambda_j y_{rj} \geq \phi_r y_{r0}; \qquad (r = 1,2,..., m);$$

$$\sum_{j=1}^{N} \lambda_j x_{ij} \leq \theta_i x_{i0}; \qquad (i = 1,2,..., n); \qquad (10)$$

$$\sum_{j=1}^{N} \lambda_j = 1; \quad \lambda_j \geq 0; \quad (j = 1,2,..., N).$$

Note that the efficient input-output projection *(x^*, y^*)* satisfies

$$x^* = \sum_{j=1}^{N} \lambda_j^* x^j \leq x^0 \qquad \text{and} \qquad y^* = \sum_{j=1}^{N} \lambda_j^* y^j \geq y^0 .$$

Thus, *(x^0, y^0)* is Pareto-Koopmans efficient, if and only if $\phi_r{}^* = 1$ for each output *r* and $\theta_i{}^* = 1$ for each input *i*, implying $\gamma(x^0, y^0) = 1$.

Pastor, Ruiz, and Sirvent (PRS) (1999) and Tone (2001) introduced essentially the same measure of overall efficiency and called it a slack based measure (SBM). The objective function in (10) is non-linear. Both PRS and Tone transformed this linear fractional functional programming problem into an LP problem by normalizing the denominator to unity. Alternatively, as shown in Ray (2004), one may replace the objective function by a linear approximation

$$.\,\gamma(x^0, y^0) = f(\theta, \varphi) \approx f(\theta^0, \varphi^0) + \tfrac{1}{n}\sum_i \theta_i - \tfrac{1}{m}\sum_r \varphi_r \approx 1 + \tfrac{1}{n}\sum_i \theta_i - \tfrac{1}{m}\sum_r \varphi_r . \qquad (11)$$

using $\theta_i^0 = 1$ for all *i* and $\phi_r^0 = 1$ for all *r* as the point of approximation. We may, therefore, replace the objective function in (10) by (11) and solve (10) iteratively using the optimal solution from each iteration as the point of approximation for the next iteration until convergence. Once we obtain the optimal (θ^*, ϕ^*) from this problem, we evaluate

$$\gamma(x^0, y^0) = \frac{\frac{1}{n}\sum_i \theta_i^*}{\frac{1}{m}\sum_r \phi_r^*} \qquad (12)$$

as a measure of the Pareto-Koopmans efficiency of (x^0, y^0).

We can visualize the Pareto-Koopmans global efficiency measure as the product of two factors. The first is the input-oriented component

$$\gamma_x = \tfrac{1}{n}\sum_i \theta_i \qquad (13a)$$

and the second is an output-oriented component

$$\gamma_y = \frac{1}{\frac{1}{m}\sum_r \phi_r}. \qquad (13b)$$

Thus, $$\gamma(x^0, y^0) = \gamma_x . \gamma_y. \qquad (14)$$

Apart from an overall measure, (12) also provides information about the potential for reducing individual inputs (θ_i^*) and increasing individual outputs (φ_r^*). Also a decomposition of (12) into the input- and output-oriented components can be obtained from (12).

3. The Empirical Analysis

3.1 The Data

This study visualizes a two-output and seven-input production technology for Indian agriculture.

The two outputs are: (a) food grains and (b) non food grains. The inputs included are:

(i) Land, (ii) Fertilizers; (iii) Irrigated Area; (iv) Pump sets ; (v)Tractors(vi) Electricity; and (vii) Labor. Further, the actual amount of rainfall is also treated as a non-discretionary input.

Sixteen major Indian States has been considered and are classified into four regions:

(A) Eastern Region : Assam (AS), Bihar (BI), Orissa (OR), and West Bengal (WB);

(B) Northern Region: Haryana (HA), Himachal Pradesh (HP),Jammu and Kashmir (JK),, Punjab (PU) and Uttar Pradesh (UP);

(C) Southern Region: Andhra Pradesh (AP), Karnataka (KA), Kerala (KE), and Tamil Nadu (TN);

(D) Western Region **:** Gujarat (GU), Madhya Pradesh (MP), Maharashtra (MH), and Rajasthan (RA).

Data used in this study have been collected from the different issues of *Statistical Abstracts* published by Central Statistical Organization (CSO) of India, www.indianstat.com, Center for Monitoring the Indian Economy (CMIE), *Agricultural Statistics at a Glance*, and *Agriculture in Brief* published by the Central Statistical Organization, different issues of *Census of India*, National Sample Survey (NSS) Reports, and Financial Accounts, Government of India, Publication.

3.2 The Empirical Findings

Estimated state-wise average levels of overall productive efficiency and its two principal components, input and output efficiencies, are presented in Table 1. More detailed breakup of the input and output efficiencies are reported in Tables 2.1-2.3.

Overall productive efficiency and its components

The overall productive efficiency and its components are presented in Table1. At the All-India level the level of output technical efficiency ((OTE), averaged over all years and all states, was 0.8549 implying that on average output was about 85.5% of the Pareto optimal level. Similarly, the level of input-oriented technical efficiency was 0.8603. That is, about 14% reduction in the average level of inputs would be possible. The overall level of Pareto Koopmans (PK) efficiency was 75.45%. Among the individual states, Uttar Pradesh (UP) showed the highest level of Pareto-Koopmans efficiency; West Bengal (WB) was a close second. Both states achieved overall efficiency above 96%. Three other states, Tamil Nadu (TN), Punjab (PU), and Assam (AS) were more than 90% efficient. At the other extreme, Gujarat (GU), and Jammu & Kashmir (JK) had efficiency below 50%; Kerala (KE) and Rajasthan (RA) were slightly above 50%. At the regional level, the Eastern region performed the best and the Western Region did the worst. In view of this, a nearly 90% overall efficiency of Maharashtra (MH), a Western state was quite remarkable.

Overall input efficiency varied from a high of 0.975 for West-Bengal (WB) to a low of 0.693 for the state Kerala (KE). The all-India average was 0.858. At the regional level**,** the overall input efficiency is highest in the Eastern region (0.918), followed by the Northern region (0.886). By contrast, Western region (0.829) and lowest in the Southern region (0.803) performed much worse. At the state level, input efficiency was the highest in Uttar Pradesh (UP) and West Bengal (WB) exceeding 97% in both cases. Punjab (PU), Assam (AS)Tamil Nadu (TN), and Maharashtra (MH) all had input efficiency above 90%. Surprisingly, however, so did two other states – Bihar (BI) and Madhya Pradesh (M) – even though their overall Pareto efficiency scores were quite low.

Average output technical efficiency (OTE) was slightly below the input technical efficiency (ITE). This comparison hides the fact that for most states, output efficiency was higher than the input efficiency. In Madhya Pradesh (MP) output efficiency was only 75.6% whereas input efficiency was 91.5%. Similarly, in Rajasthan (RA) output efficiency was 62.8% while input efficiency was 81.2% In Bihar (BI) and Jammu & Kashmir (JK) output efficiency was lower than input efficiency by over 8 percentage points. Despite these individual cases most Indian states performed better in respect of realizing the potential outputs than in conserving the surplus inputs.

Input Efficiency

Tables 2.1 and 2.2 provide more details on the on the components of input technical efficiency. As noted at the beginning, introduction of modern inputs was an integral part of the new agricultural strategy in the Green Revolution era. In light of this, we divided the agricultural inputs into two broad categories: modern and traditional. Included in the modern category are: (i) fertilizers, (ii) pumps, (iii) tractors, and (iv) (electric) power. The other inputs: (a) labor, (b) irrigation, and (c) land are treated as traditional inputs. Use of chemical fertilizers, pumps for deep well irrigation, tractors and tillers, and electric power are the hallmarks of the new technology. Of course, there is some measure of overlap in the sense that irrigation in the traditional category relies on deep wells as the source and, hence, to a considerable extent, is closely related to pumps (and power). As can be seen from Tables 2.1 and 2.2, while utilization of the traditional inputs was reasonably high, the modern inputs were considerably under-utilized. At the All-India level, the average rate of under-utilization of modern inputs was

20.7% Given that these non-traditional inputs account for a large part of the paid out costs in farming, this is quite disturbing.

For any individual input, the input-specific technical efficiency of any particular state (reported in Table 2.1) shows what proportion of the actual quantity of that input used would be required if the state operated at the selected Pareto-Koopmans efficient point on the frontier. Only 5 states, Bihar (BI), West Bengal (WB), Punjab (PU), Uttar Pradesh (UP), and Tamil Nadu (TN), had average input efficiency over 90% for the modern inputs. The All-India average was even lower than 80% implying that over a fifth of the actual input bundle was being wasted. At the individual input level, efficiency was lowest for power (73.76%). For fertilizer, it was still below 80%. The strikingly low numbers for Gujarat (GU) may have been due to some data problem (although data errors over all inputs and all years appear to be highly unlikely). But even when we exclude Gujarat, the average improved only marginally. In the case of fertilizers, Jammu & Kashmir (JK), Kerala (KE), Gujarat (GU) had efficiency below 45% while Karnataka (KA) was at the 53% level. For pumps, Gujarat had efficiency below 40% and Kerala (KE) barely exceeded 50%. But most other states were quite efficient. For tractors, Jammu & Kashmir (JK), Karnataka (KA), Kerala (KE), and Gujarat (GU) performed poorly. Others were fairly to highly efficient. In the case of power, Jammu & Kashmir (JK), Karnataka (KA), Kerala (KE), and Gujarat (GU) had very low efficiency. Orissa (OR) and Andhra Pradesh (AP) also had over 35% under-utilization of the power input. Region-wise, the Southern states had efficiency below 65% for fertilizer and power. Tamil Nadu (TN) was an exception. Western states had efficiency barely above 65% in case of power. Low efficiency rating of the Western region is mainly driven by Gujarat (GU).

Low input specific efficiencies in respect of the modern inputs contrast sharply with traditional inputs where except for Bihar (BI) in respect of labor and Jammu & Kashmir (JK) in respect of irrigation, input efficiencies are uniformly high. It would be worthwhile to examine if government subsidization of fertilizer and power inputs account for avoidable waste in these inputs found in Table 2.1.

Output Efficiency

Table 2.3 shows the decomposition of the overall output efficiency into separate components for food grains and other ((non-food grain) crops. For food grains, output efficiency is above 90% for all states other than Kerala (KE), and Gujarat (GU). By comparison efficiency in the production of other crops is much lower. Jammu & Kashmir (JK) (25.27%), Gujarat (GU) (56.89%). Andhra Pradesh (AP) (62.48%) and Bihar (BI) (65.73%) are the most inefficient states in this respect.

While a high average level of output efficiency in respect of food grains is good news, it also carries an implicit warning that there is not much room for increasing food supply within the present technological frontier. In view of the increasing level of commercialization of agriculture in India, the poor performance observed in respect of the other crops is somewhat puzzling. It is possible that because most of these products (like cotton and jute fiber) are produced as industrial raw materials, demand fluctuation in the relevant industries may restrict production well below the full potential. This, of course, is only a speculation that can be verified only with crop specific data. That is beyond the scope of the present study.

Efficiency over time

Another question that we address in this study is whether there is any clear pattern in how input or output specific efficiency levels have changed over time. The findings in this respect are reported in Table 3. To eliminate the random noise often found in year-to-year variations in efficiency, we focus, instead, on average levels of efficiency over 5-year periods. In the first half of the 1970s, both input and output efficiencies were quite high. Further. The rate of utilization of modern inputs exceeded 91%. On the output side, both food grains and other crops showed high efficiency. One may argue that the Green Revolution got off to a good start. During the latter half of the 70s, even though efficiency with respect to modern inputs on the one hand and non-food crop output on the other showed a slight decline, overall input and output efficiencies both remained above 90%. The next decade saw a drastic drop in efficiency with respect to modern inputs as well as non-food output. Both of them were between 72% and 74%. Particularly low were the utilization rates of fertilizer and power inputs. During the first half of the 1990s, there was some improvement in respect of modern inputs overall but efficiency in the utilization of power remained below 70%. Over the last half of the 1990s, things worsened. Quite low efficiency is found for tractors and power. For the first time, output efficiency fell below 90% for food grains. All in all, there is a decline in input and output efficiencies over time. This is particularly noticeable for non-food crops and for some modern inputs (especially, fertilizers and power).

4. Explaining the variation Pareto- Koopmans Efficiency

Modernization of traditional agriculture involves numerous structural changes at different levels. The most important of them is replacement of age old farming parctices by a more advanced and knowledge based technology. As noted by Dantwala (1967, 1970), there are other concomittant changes like commericialization of a predominantly subsistence agriculture through integration of an isolated village based economy into a national and eventual global economy and breaking up rural monopolies in land though a more eaglatarian distribution.

In the post-Green Revolution era, the newly introduced high yielding variety seeds and chemicial fertilizers have greatly enhanced the importance of assured supply of water through deep well and canal irrigation. Although government and private irrigarion have complimentary roles to play, commodification of water as a purchased input supplied from private sources has played a major role (as in the case of winter rice, *Boro*, in West Bengal). Other kinds of physical infrastructures (like road and rail communication facilities, telephones, network of power lines in rural areas, etc) also enhance productive efficiency.

Government expenditure on agricultural education, research, and extension contributes to human capital formation and facilitates transtion from traditional to modern technology. Eeven the spread of basic education (raising the rural literacy rate) contributes towards increase in human capital. Because of the growing importance of purcahsed inputs, easy and timely availability of agriocultural credit is also conducive to increasing efficiency.

It is well known that trade liberalization provides many benefits such as increase in market size, knowledge of demand characteristics in foreign markets, information about new technologies, process and products and cost reductions and quality improvements. Also the gains from trade can arise because of (a) movements to existing production possibility frontiers (due to technical efficiency), (b) movement along the existing frontiers because of new trading opportunities and (c) upward shift of the frontier (due to learning, application of improved technologies and adoption of better farming practices. As explained below, a state with a higher (weighted) share of its agricultural products in the country's exports benefits more from liberalized trade policies.

At the individual producer level, crop diversification makes the farmer more competitive allowing it to access the market for a greater number of products. Further, diversification lowers risk and fosters commercialization allowing the farmer to step outside the bounds of what once was described as the "survival algorithm" when producing enough food crop for subsistence was the highest priority.

Finally, land reforms and lowering the concentration of ownership is a well documented engine of productivity and efficiency growth in agriculture. There are several individual country studies that explore the possible connection of land distribution and productivity. Besley and Burgess (2000) finds that land reforms had their greatest effect in those Indian states with greatest initial land inequality. Jeon and Kim (2000) document significant productivity gains from land reforms undertaken in Korea in the 1950s which limited the amount of land any individual can own. Banerjee and Iyer (2005) examining the historical nature of land distribution in India find that those Indian states with higher initial land inequality had lower productivity even after land reform took place. Vollarth (2007) addresses the issue of land distribution and international agricultural productivity by using cross country data on inequality in operational holding of agricultural land reform from Deininger and Squire (1998).In an estimation of an agricultural production function , the Gini coefficient for land holdings is found to have a significant negative relationship with productivity.

In view of the above, we specified a log-linear regression with the Pareto-Koopmans efficiency (PK) as the dependent variable and (a) Gini ratio of land distribution (GINI), (b) degree of openness (OPEN), (c) government spending on agricultural education and research (EDUR), (d) acreage under private irrigation (PI), (e) acreage under government (canal) irrigation (GI), (f) availability of agricultural credit (LOAN), (g) crop diversification index (CDI), (h) rural literacy rate (RLR), and a physical infrastructure index (INFR) as explanatory variables. Each state in the sample was treated as a unit of observation.

Data construction was carried out as follows.

- The Gini ratio was constructed from the Census of agriculture.
- Degree of openness was constructed in the following way. Let the country export R number of agricultural goods and net export of each commodities be E_1, E_2 ……..E_R .Let E be the net export of the country. Then $m_1 = E_1/E$, $m_2 = E_2/E$,..,$m_R = E_R/E$, be the share of each commodities in total net export basket. Suppose that

there are j = 1, 2 ….. n number of states in the country and s_{ij}, i = 1, 2 ….. R, j = 1, 2 …. n is the value share of crop i in total agricultural production of state j. Then the index of openness for the state j can be constructed as

$$OPEN = s_{1j}m_1 + s_{2j}m_2 + ... + s_{Rj}m_R.$$

- The amount of Government expenditure on agricultural education and research is normalized by dividing it total area under agricultural operation and is denoted as EDUR.
- Private and government irrigation is measured by the proportion of irrigated area under the two kinds of irrigation.
- Agricultural credit (LOAN) is measured by the total amount of credit issued by rural banks and agricultural cooperatives per acre of cultivated area in the state.
- Crop diversification index (CDI) is the Hirshmann-Harfindahl index of diversification of land allocated to different crops.
- Rural Literacy Rate comes from the Census.
- The physical infrastructure index is taken from data constructed by Ghosh and De using Principal Component Analysis (1998).

The preferred estimated model is reported in the following table:

OLS Regression of Pareto-Koopmans Efficiency(PK)

	Explanatory variables	coefficients	t-ratio	p-value	R^2
Dependent variable LPK	LGINI	-0.96394	-1.7814	0.1127	0.4788
	LOPEN	1.0961	2.1815	0.0607	
	LEDUR	0.25407	2.0102	.0793	
	LRLR	1.3694	1.4896	0.1747	
	LPI	6.5509	1.2804	0.2363	
	LGI	2.8592	1.1827	0.2709	
	LCDI	0.046948	1.3226	0.2225	
	CONSTANT	-10.612	-1.6180	.1443	

Here LPK, LGINI, LOPEN, LEDUR, LRLR, LPI, LGI, LCDI denote the log of the respective variables. Two explanatory variables, degree of openness and government expenditure on agricultural research and extension, have t-values than 2.0 and are significant at 6 % and 7 % level of significance respectively. Both of them have positive impact on efficiency. GINI

Coefficient is significant at 11% level of significance and has the anticipated negative sign. A higher concentration of land ownership lowers efficiency. Rural literacy rate has a positive coefficient that is significant at the 17.5% level.. The other explanatory variables are significant between 22% to 27% levels of significance. Private irrigation has a greater impact on efficiency than government irrigation. All of the coefficients have ‘t’ ratios well in excess of unity. The R^2 of the model is a moderate 47.8%.

We may now summarize the main findings from the empirical analysis:

- There is strong evidence of an overall decline in both input- and output efficiencies over time. It is particularly true of the modern inputs and non food crops. Thus, although the use of fertilizers, agricultural machinery, and power has increased phenomenally over years, rates of productive utilization of the inputs has fallen. Because use of these modern inputs is an integral part of the modern technology, potential benefits of the technological change remain unrealized to a considerable extent.
- There is little room for increasing food production simply through improved efficiency. Relatively high rates of utilization of traditional inputs (especially land and irrigation) suggest that these are the inputs that could limit increasing output without another technological breakthrough.
- There is considerable inter-regional variation in the levels of input- and output-specific efficiencies. This is particularly true for modern inputs and non-food output. The Eastern Region performs the best in terms of both input and output efficiency. Further, the average input and output efficiencies are approximately equal in this region. This is true of the Northern Region also, which also shows high average efficiency. The other two regions, Western states have a higher input efficiency while the Southern states have a higher average level of output efficiency.
- Although fertilizers and power are the two inputs that largely account for the low levels of efficiency (i.e., utilization) of modern inputs, there is considerable variation across regions (and states within regions). For the Eastern Region, efficiency is highest for tractors and for the other three modern inputs it is about equal. In the Northern Region, efficiency is highest for pumps and about equal for the other three inputs. In the

Southern Region, efficiency is lower for fertilizers and power. Finally, in the Western Region, efficiency is highest for fertilizers and lowest for power.

Based on the regression analysis reported above, the following policy recommendations for improving overall technical efficiency can be made:

- The government should increase expenditure on agricultural education and research.
- Trade liberalization policy should be aggressively pursued.
- The government should carry out land reform in order to lower the inequality in land ownership.
- Policies to raise the literacy rate among the rural population will increase efficiency.
- Private irrigation schemes should be supported and encouraged through appropriate incentives. Public irrigation projects should be viewed as complementary to rather than substitutes for private irrigation.
- Crop diversification should be encouraged through agricultural extension programs as well as easier access to credit.

It is advisable to recognize, at this point, some limitations of the data used and to acknowledge that the results should be interpreted with some caution. In the first place, we are using highly aggregated data. Not only are the input-output data aggregates over all farms in a state, they are also aggregated over crops and, hence, across different varieties of any crop (like traditional and high yielding varieties of rice or wheat). Similarly, inputs (like fertilizers) are also aggregated. Despite this limitation, our 2-output multi-input framework is more disaggregated than what is found in the relevant literature.

Another important point to remember is that state level efficiency measures computed for each year are based on the input-output data for that particular year only. In the jargon of Data Envelopment Analysis, these are efficiencies relative to a *contemporaneous frontier*. No attempt is made to measure efficiency against "cross-period frontiers". This circumvents the question of technical progress. Finally, although we have efficiency measures by state and year, similar year- and state-wise information about the explanatory variables is not available. This ruled out a (2-way fixed effects) panel regression. We had to settle, instead, for a regression using the mean of the dependent and independent variables.

In spite of these limitations, evidence of the downward movement in overall efficiency as well as in output and input efficiencies is quite convincing.

5. Conclusion

It is well known from the general theory of diffusion of both ideas and products that there are four distinct stages in the process. The new idea is first embraced by *innovators*, the small percentage of the relevant population who dare to try something new. Then come the *early adopters*, the more careful segment who prefer to wait-and-see first. Next are the *late adopters*, who are mainly driven by the example of others. Finally enter the *laggards*. In the case of the Green Revolution, it is reasonable to argue that the more productive farmers with greater human capital came first. Over time, the less productive ones followed. This is a reasonable explanation of the decline in efficiency (especially for modern inputs and cash crops) over time. In any event, it seems to be the case that Indian agriculture is likely to remain stagnant unless a new breakthrough in the technology takes place.

**Table 1: Output-, Input-, and overall Efficiencies:
(by Region and State)**

Region/State	OTE	ITE	PK
Eastern	0.9272	0.9178	0.8589
AS	0.9864	0.9295	0.9197
BI	0.8287	0.9140	0.7654
OR	0.8974	0.8574	0.7827
WB	0.9963	0.9702	0.9677
Northern	0.8807	0.8858	0.8030
HA	0.9198	0.8898	0.8237
HP	0.8884	0.8922	0.8102
JK	0.6263	0.7086	0.4682
PU	0.9706	0.9503	0.9264
UP	0.9985	0.9880	0.9866
Southern	0.8565	0.8026	0.7047
AP	0.8021	0.8327	0.6806
KA	0.9325	0.7506	0.7063
KE	0.6965	0.6931	0.5012
TN	0.9951	0.9339	0.9308
Western	0.7487	0.8289	0.6393
GU	0.6415	0.6694	0.4303
MH	0.9699	0.9151	0.8927
MP	0.7560	0.9189	0.7077
RA	0.6276	0.8121	0.5263
All-India	0.8549	0.8603	0.7545

Table 2.1 Efficiency in the Use of Modern Inputs (by Region and State)

Region/State	fertilizer	pump	tractor	power	modern
Eastern	0.8823	0.8998	0.9523	0.8597	0.8985
AS	0.8660	0.9127	0.9210	0.8482	0.8870
BI	0.9001	0.9283	0.9291	0.9737	0.9328
OR	0.8102	0.8170	0.9845	0.6495	0.8153
WB	0.9527	0.9410	0.9745	0.9673	0.9589
Northern	0.7968	0.9484	0.7846	0.7943	0.8310
HA	0.8355	0.8758	0.7516	0.8565	0.8298
HP	0.8025	0.9552	0.7463	0.7870	0.8228
JK	0.4117	1.0000	0.5795	0.4105	0.6004
PU	0.9350	0.9632	0.8782	0.9274	0.9259
UP	0.9995	0.9480	0.9673	0.9899	0.9762
Southern	0.6139	0.7439	0.7709	0.6312	0.6900
AP	0.6051	0.8443	0.9973	0.6043	0.7627
KA	0.5300	0.7248	0.5654	0.5312	0.5879
KE	0.4392	0.5022	0.5377	0.5148	0.4985
TN	0.8811	0.9045	0.9831	0.8744	0.9108
Western	0.8354	0.7552	0.7499	0.6561	0.7492
GU	0.4357	0.3978	0.7447	0.2894	0.4669
MH	0.9203	0.9216	0.8501	0.8216	0.8784
MP	0.9855	0.9250	0.7935	0.8135	0.8794
RA	1.0000	0.7764	0.6114	0.7000	0.7720
All-India	0.7818	0.8434	0.8109	0.7376	0.7934

Table 2.2 Efficiency in the Use of Traditional Inputs (by Region and State)

Region/State	Labor	Irrigation	land	traditional
Eastern	0.9073	0.9376	0.9857	0.9385
AS	1.0000	0.9728	0.9864	0.9660
BI	0.7106	0.9606	0.9956	0.8889
OR	0.9283	0.8515	0.9608	0.9135
WB	0.9905	0.9657	1.0000	0.9854
Northern	0.9692	0.9266	0.9896	0.9618
HA	1.0000	0.9430	0.9667	0.9699
HP	0.9638	1.0000	0.9902	0.9847
JK	0.8879	0.7405	1.0000	0.8761
PU	1.0000	0.9571	0.9910	0.9827
UP	0.9945	0.9925	1.0000	0.9957
Southern	0.8993	0.9890	0.9872	0.9585
AP	0.8650	0.9941	0.9872	0.9488
KA	0.9206	1.0000	0.9824	0.9677
KE	0.8823	0.9967	0.9792	0.9527
TN	0.9292	0.9649	1.0000	0.9647
Western	0.9620	0.9597	0.8838	0.9351
GU	0.9876	0.9493	0.8812	0.9394
MH	0.9360	1.0000	0.9563	0.9641
MP	0.9306	0.9917	0.9922	0.9715
RA	0.9937	0.8979	0.7054	0.8656
All-India	0.9302	0.9528	0.9643	0.9491

Table 2.2 Efficiency in the Production of Outputs (by Region and State)

Region/State	Food	non-food	output
Eastern	0.9960	0.8634	0.9271
AS	1.0000	0.9927	0.9863
BI	1.0000	0.6573	0.8287
OR	0.9914	0.8034	0.8974
WB	0.9925	1.0000	0.9963
Northern	0.9927	0.7686	0.8806
HA	0.9633	0.8763	0.9198
HP	1.0000	0.7768	0.8884
JK	1.0000	0.2527	0.6263
PU	1.0000	0.9412	0.9706
UP	1.0000	0.9959	0.9979
Southern	0.8984	0.8147	0.8565
AP	0.9793	0.6248	0.8021
KA	0.9095	0.9555	0.9325
KE	0.7138	0.6792	0.6965
TN	0.9909	0.9993	0.9951
Western	0.9023	0.5952	0.7487
GU	0.7141	0.5689	0.6415
MH	0.9459	0.9938	0.9699
MP	0.9962	0.5159	0.7560
RA	0.9531	0.3021	0.6276
All-India	0.9500	0.7598	0.8549

Table 3 Mean levels of Input-, Output-, and Overall Efficiency (by sub-periods)

sub-period	71-2/75-6	76-7/80-1	81-2/85-6	86-7/90-1	91-2/95-6	96-7/00-1
ITE	0.9435	0.9049	0.8208	0.8293	0.8554	0.8069
modern	0.9185	0.8555	0.7212	0.7397	0.7833	0.7423
fertilizer	0.9153	0.8576	0.6988	0.7138	0.7500	0.7555
pump	0.9361	0.8597	0.7561	0.7890	0.8352	0.8843
tractor	0.9197	0.8593	0.7421	0.7782	0.8489	0.7170
power	0.9028	0.8456	0.6878	0.6777	0.6991	0.6126
traditional	0.9768	0.9708	0.9536	0.9489	0.9515	0.8931
labor	0.9829	0.9654	0.9192	0.9134	0.9348	0.8656
irrigation	0.9688	0.9771	0.9745	0.9670	0.9524	0.8769
land	0.9788	0.9698	0.9671	0.9664	0.9671	0.9368
OTE	0.9441	0.9133	0.8581	0.8175	0.8492	0.7470
food	0.9768	0.9708	0.9536	0.9489	0.9515	0.8931
non-food	0.9185	0.8555	0.7212	0.7397	0.7833	0.7423
PK	0.9056	0.8392	0.7195	0.6961	0.7495	0.6159

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