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Decomposition of Technical Change and Productivity Growth in Indian Agriculture Using Non-Parametric Malmquist Index

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Abstract

The present study endeavors to analyze the rate of total factor productivity growth and technical progress of Indian Agriculture between the period 1971 to 2004, using a Data Envelopment Analysis. It has been observed that that the productivity growth of Indian agriculture is negative, thus confirms that the entire output growth is contributed by input growth. The decomposition of productivity growth into efficiency change and technical progress reveals that the efficiency change is positively contributing towards the growth of productivity whereas, the negative growth of technology restrict the potential productivity growth in Indian agriculture. Further, it has also been observed that efficiency change is insignificant whereas, the technical change is of Hicks non-neutral type in Indian agriculture.

Keywords: *Total Factor Productivity, Overall Efficiency, Input Biased Technical Change, Scale Efficiency Change, Malmquist Productivity Index.*

JEL Code Classification: *D24, O30, Q19*

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1. Introduction

Productivity growth in agriculture sector is considered important to the development process, allowing countries to produce more food at lower cost, improve nutrition and welfare, and release resources to other sectors. The Total Factor Productivity (TFP) growth, traditionally calculated as the ratio of total output to the weighted sum of inputs, is quite often interpreted as a shift of the production function. This interpretation is valid only if the farmers are technically efficient in production and are realizing the full potential of the given technology. Technically efficient production can be achieved if farmer follow the best practice to apply the technology. To the extent that farmers do not produce with technical efficiency due to differences in their capacity to use new technological knowledge, technical progress is not the only source of total factor productivity growth. Therefore, the changes in productivity may arise from two components technical progress *viz-a-viz* efficiency change. However, from policy point of view the decomposition of total factor productivity is important as it provides a useful statistic to indicate how economic welfare in general and agricultural development in particular is being advanced through productivity gains in agriculture.

The total factor productivity growth is defined as the residual growth in outputs not explained by the growth in input use is, often measured by two approaches i.e. growth accounting formula (Solow, 1957) and index number approach. (Tornquist, 1936 and Malmquist, 1953) The selection of later approach over the former one is because of some conceptual and empirical problems related to input and output measurement (Griliches (1987). However, the choice of c over the Tornquist index is mainly because the Malmquist index do not requires quantity and price information and assumptions about the structure of technology and the behavior of producers.

The Malmquist productivity index, defined as a ratio of distance functions represents multi-output and multi-input technologies and requires data only on input and output quantities (Fare et al. 1994). The index gained considerable popularity in past couple of years due to its appealing feature of allowing a further decomposition of productivity variation. Therefore, to examine the sources of TFP growth of Indian agriculture in generally and for the fourteen major agricultural states particularly, the Malmquist index and its components has been calculated by using the mathematical programming procedure outlined in Fare et.al. (1994).

2. Malmquist Productivity Index: A Methodological Framework

In this section the concept and methodology used to measure TFP growth of Indian agriculture has been defined. For the output-based Malmquist index we assume, as in Fare et al. (1998), that for each time period t=1,. . .,T, the production technology describes the possibilities for the transformation of inputs X^t into outputs Y^t.

This is the set of output vectors that can be produced with input vector X. For the technology in period t and with $y^t \in R_+^m$ outputs and $x^t \in R_+^n$ inputs:

Pt(x) = {yt: Such that xt can produce yt}

The output distance function is defined at period t as the reciprocal of the maximum proportional expansion of output vector yt given input xt

$$D_0^t(x^t, y^t) = \inf\left\{\phi : \left(x^t, \frac{y^t}{\phi}\right)\right\} \in P(x^t)$$

where φ is the coefficient dividing yt to get a frontier production vector at period t given xt.

The Malmquist index can be defined using distance functions. Depending on the technology used as the reference, we can define a period t-based or a period (t + 1)-based Malmquist index. The period t-based Malmquist index is defined as

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

Using the technology at t + 1 as the reference, the period (t + 1)-based Malmquist index is defined as:

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

In order to avoid choosing the MPI of an arbitrary period Färe et al. (1994) specified the Malmquist productivity change index as the geometric mean of equations (1) and (2) referred as the ‘‘Fare index’’

$$M_0 = \sqrt{M_0^t * M_0^{t+1}} = \sqrt{\frac{D_0^t\left(x^{t+1}, y^{t+1}\right)}{D_0^t\left(x^t, y^t\right)} * \frac{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_0^{t+1}\left(x^t, y^t\right)}}$$

Following Fare et al. (1994) the Fare index can be decomposed into efficiency change technical change components, and the results applied to the different period-based Malmquist indices.

The decomposition for the three indices in Table 1 reveals that the efficiency change index is the same for all of the three Malmquist indices whereas the indices differ in measure of technical change (shift in the frontier). The index M_0^t measures the shift in the frontier along a ray through the origin and the production point in t + 1 and the index M_0^{t+1} measures the shift in the frontier through the production point in t. It is important to note here that the technical change component of the Fare index is just the geometric mean of the technical change components in M_0^t and M_0^{t+1}. A value of the efficiency change component of the Malmquist index greater than 1 means that the production unit is closer to the frontier in period t + 1 than it was in period t, i.e. the production unit is catching up to the frontier. However, a value less than 1 indicates efficiency regress. The same range of values is valid for the technical change component of total productivity growth, meaning technical progress when the value is greater than 1 and technical regress when the index is less than 1.

Table 1: Decomposition of Malmquist Index into Efficiency Change and Technical Change Components

Index	Efficiency Change	Technical Change	Characteristics
Period t Based Malmquist M_0^t	$\frac{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_0^t\left(x^t, y^t\right)}$	$\frac{D_0^t\left(x^{t+1}, y^{t+1}\right)}{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)}$	TECH measures the shift in the frontier along a ray through the production point in t+1.
Period t+1 Based Malmquist M_0^{t+1}	$\frac{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_0^t\left(x^t, y^t\right)}$	$\frac{D_0^t\left(x^t, y^t\right)}{D_0^{t+1}\left(x^t, y^t\right)}$	TECH measures the shift in the frontier along a ray through the production point in t.
Fare Index	$\frac{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_0^t\left(x^t, y^t\right)}$	$\sqrt{\frac{D_0^t\left(x^{t+1}, y^{t+1}\right)}{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)} * \frac{D_0^t\left(x^t, y^t\right)}{D_0^{t+1}\left(x^t, y^t\right)}}$	TECH is the geometric mean of TECH in M_0^t and M_0^{t+1}. EFCH is the same for the three indices.

Notes: i) Where Malmquist Index = EFCH*TECH; ii) EFCH measures the gap between actual production and maximum production with given inputs; iii) TECH measures the shift in technology between the two periods (Technical Change). Source: Nin et al.2003.

In order to calculate the M0 for state k' between t and t+1 for a constant returns-to-scale (CRS) technology, the four different distance functions that make up the index, that is, $D_o^t(x^{k',t}, y^{k',t})$, $D_o^{t+1}(x^{k',t+1}, y^{k',t+1})$, $D_o^t(x^{k',t+1}, y^{k',t+1})$, and $D_o^{t+1}(x^{k',t}, y^{k',t})$ are required to be calculated using linear programming approach. For calculating output-oriented distance functions for the agriculture sector of state k', four different linear programming problems can be stated as:

$$\left.\begin{aligned}
&D_o^{t+j}(x^{k',t+j}, y^{k',t+j})^{-1} = \max\ \theta^{k'} \\
&\text{subject to} \\
&\theta^{k'} y_m^{k',t+j} \le \sum_{k=1}^{K} z^{k,t+i} y_m^{k,t+i}, && m = 1,\ldots,M; \\
&\sum_{k=1}^{K} z^{k,t+i} x_n^{k,t+i} \le x_n^{k',t+j}, && n = 1,\ldots,N; \\
&z^{k,t+i} \ge 0, && k = 1,\ldots,K.
\end{aligned}\right\} \ldots\ldots\ldots\ldots(3)$$

Where (i,j)=(0,0) for solving for $(D_o^t(x^{k',t}, y^{k',t}))^{-1}$;

(i,j)=(1,1) for solving for $(D_o^{t+1}(x^{k',t+1}, y^{k',t+1}))^{-1}$;

(i,j)=(0,1) for solving for $(D_o^t(x^{k',t+1}, y^{k',t+1}))^{-1}$; and

(i,j)=(1,0) for solving for $(D_o^{t+1}(x^{k',t}, y^{k',t}))^{-1}$.

In the above linear programming problems, $z^{k,t}$ is an intensity variable indicating the intensity at which a particular state is employed in constructing the frontier of the technology set. The technology specified here is non-parametric but assumes constant returns-to-scale and strong disposability of inputs and outputs. In above formulation θ is the efficiency score and take value between 0 and 1. Following Afriat (1972), one may allow for variable returns to scale (increasing, constant or decreasing) by having $\sum Z_k = 1$ as a restriction in all of the linear programs. Thus, by estimating the distance functions defined by model (3) along with the restriction $\sum Z_k = 1$, we can decompose the EFCH into into pure efficiency change (PEFCH) and scale efficiency change (SEFCH) as follows.

$$EFCH = PEFCH * SEFCH$$

Where

$EFCH = \dfrac{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_0^t\left(x^t, y^t\right)}$; $PEFCH = \dfrac{D_V^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_V^t\left(x^t, y^t\right)}$; and

$SEFCH = \dfrac{D_C^{t+1}\left(x^{t+1}, y^{t+1}\right)}{D_V^t\left(x^{t+1}, y^{t+1}\right)} * \dfrac{D_C^t\left(x^t, y^t\right)}{D_V^t\left(x^t, y^t\right)}$[1]

Following Fare and Grosskopf (1996), we can decompose the technical change, by estimating two additional distance functions $(D_o^t(x^{k',t+1}, y^{k',t}))^{-1}$ and $(D_o^{t+1}(x^{k',t+1}, y^{k',t}))^{-1}$, into a bias term and a magnitude term. The bias term is further decomposed in an output biased technical change (OBTECH) component and an input biased technical change (IBTECH) component.

The output biased component measures the shift in the frontier along a ray through y^{t+1} relative to a measure of the shift in the frontier along a ray through y^t. In order to capture the output bias, the input vector is fixed at the t + 1 value. Similarly, the input biased component measures the shift in the frontier through x^{t+1} relative to a measure of the shift in the frontier through x^t, fixing

[1] Subscripts C and V represents the constant returns to scale and variable returns to scale respectively.

the output vector at the t value. Output neutral technical change implies OBTECH = 1 and input neutral technical change results when IBTECH = 1. Under the Hicks joint neutrality, BTECH = OBTECH*IBTECH = 1 and the magnitude component equals the technical change component. In this particular case the three Malmquist indices will result in the same estimate of technical change. However, in the case of single output[2] biased component equal to unity and thus, technical change is product of input bias and magnitude. Following Kumar (2006), the definition of Hicks neutral, capital deepening and labour deepening technical progress depends on, under constant capital-labour ratio, the marginal rate of substitution of labour for capital (MRTSL,K) remaining constant, decreasing or increasing. (Binswanger, 1974) Following Fare, Grosskopf and Lee (1995) and Weber and Domazlicky (1999) IBTECH is independent of output under CRS when states produce single output. Table 3 depicts that how value of IBTECH and change in capital labour ratio (K/L) can be used to identify the capital or labour deepening character of technical change.

Table 2: Decomposition of Technical Change into Magnitude and Biased Components

Index	Component	Characteristics
Output Biased Technical Change	$\sqrt{\frac{D_0^t\left(x^{t+1},y^{t+1}\right)}{D_0^{t+1}\left(x^{t+1},y^{t+1}\right)} / \frac{D_0^t\left(x^{t+1},y^t\right)}{D_0^{t+1}\left(x^{t+1},y^t\right)}}$	Ratio of a measure of the shift in the frontier through y^{t+1} and a measure of the shift in the frontier through y^t, fixing the vector of inputs.
Input Biased Technical Change	$\sqrt{\frac{D_0^t\left(x^{t+1},y^t\right)}{D_0^{t+1}\left(x^{t+1},y^t\right)} / \frac{D_0^t\left(x^t,y^t\right)}{D_0^{t+1}\left(x^t,y^t\right)}}$	Ratio of a measure of the shift in the frontier through x^{t+1} and a measure of the shift in the frontier through x^t, fixing the vector of outputs.
Magnitude	$\frac{D_0^t\left(x^t,y^t\right)}{D_0^{t+1}\left(x^t,y^t\right)}$	Under input and output neutrality, the magnitude component equals the technical change component

Notes: i) Where Malmquist Index = EFCH*TECH; ii) TECH = BTECH* MATECH; iii) BTECH = OBTECH* IBTECH.
Source: Nin et al. 2003

Table 3: Input Biased Technical Change Direction

	IBTECH>1	IBTECH=1	IBTECH<1
(K/L)t+1 > (K/L)t	Labour Deepening	Neutral	Capital Deepening
(K/L)t+1 < (K/L)t	Capital Deepening	Neutral	Labour Deepening

Source: Kumar(2006)

3. Data and Variables

The study is based on secondary data compiled under the scheme of Cost of Cultivation of Principal Crops in India, by Ministry of Agriculture, Government of India. The data pertaining to the period 1971 to 2004 has been taken for study purpose. However, the data pertaining to fertilizer use per hectare has been culled out from Center for Monitoring Indian Economy (CMIE) reports.

[2] Single output in the present study represents the output per hectare in monetary terms at constant prices.

The variables value of output per hectare, value of labour use per hectare, value of machine use (i.e. capital use) per hectare and fertilizer use per hectare has been utilized for the study. Since the data is available in disaggregated form (crop-wise) and because of diversity in crops due to different geographical and climatic conditions across the major agricultural states, therefore the technique of Principal Component Analysis (PCA) has been applied to work out the composite index of all crops. (Table A.4-A.6) Further, to make the figures comparable over time and across states, suitable deflators have been utilized.

4. Empirical Analysis

Table A.1 depicts the inter-temporal variation in TFP growth of Indian agriculture. The productivity in Indian agriculture has been observed declining at the rate of 3 percent per annum. The observed negative growth in Indian agriculture is matter of serious concern in the light of the argument of policy planers that a minimum 4 percent per annum growth is required to sustain the growth of 8 percent per annum of Indian economy. However, given the negative productivity growth rate, it seems difficult to carry on high economic growth rate of Indian agriculture because TFP is important component of output growth under growth accounting framework.

Further, the inter-state analysis represents that except two states namely Punjab and Karnataka, the TFP growth of rest of 12 major agricultural states is negative during the entire study period. The minimum TFP growth to the tune of (-) 6.80 percent per annum has been observed for industrially advance state i.e. Maharashtra. However, Punjab records highest TFP growth to the tune of 0.8 percent per annum. Even though the two states have registered positive TFP growth yet the stagnation has been noticed in Indian agriculture because the growth is even less than 1 percent per annum. Furthermore, it has also been found that 7 out of 14 major agricultural states registered positive TFP growth in early 1980s, but in subsequent periods there is continuous decline in TFP growth. Some authors argued that the dynamism which was generated by green revolution had worked its way fully in to production in early 1980's, and after that there was no alternative source of strong productivity growth. (Bhalla, 1995)

The analysis of impact of economic reforms on Indian agriculture depicts that the TFP growth has been improved insignificantly during the post reforms period in comparison of pre-reforms period. It observed deceleration to the tune of 5.15 percent in pre-reform period become acceleration at the rate of 0.07 percent per annum in post reforms period. The inter-state analysis of impact of economic reforms also signifies an improvement in TFP change during the post reforms period in comparison of pre-reforms period. The significant productivity growth in all the states may attribute to the reason that the gradual opening up of Indian agriculture to world markets is likely to turn the terms of trade in favour of agriculture. Further, the creation of a better incentive environment for agriculture than has been the case in preceding decades along with reforms in supply side factors like technology, fertilizers, irrigation, credit and the dismantling of all export controls on agricultural commodities including foodgrains are major reasons for significant increase in TFP growth in all the major agricultural states of India (Rao, C.H.; 1994). Moreover, the deceleration in growth of TFP has been observed both at all India level (Table A.1) and at state level during the post WTO period (i.e 1995). The negative growth of TFP may be due to the diversification from high-value crops towards low-value and less-input demanding crops because of fall in exports of primary commodities elucidate the reasonable explanation for the decline in TFP growth. However, the terms of trade for agriculture showed deterioration, and agricultural incomes were become highly unstable in recent years (ICAR Annual Report, 2009). In short the growth of agriculture is slow and completely dependent on input contribution because TFP growth fragile in nature and contribute insignificantly in growth of Indian agriculture in general and major agricultural states in particular. Hence the analysis calls for the need to analyze the results of the sources of productivity growth to detect the cause of such a fragile nature of TFP growth.

The search for the sources of productivity growth in Indian agriculture depicts that the efficiency change is positively contributing towards the growth of productivity however, the negative growth of technology restrict the potential productivity growth in Indian agriculture. Further the observed slow efficiency growth of 0.6 percent per annum with the technical regression to the tune of (-) 3.2 percent per annum is serious matter of concern for government and policy planers (Table A.1). The common phenomenon of technical regress in Indian agriculture can also be supported on the ground that the continuous falling public investments and government expenditure on research and development along with high input prices diversified the activities of farmers from high value crops to low risky and less input demanding crops and hence restrict the outward movement of frontier. Moreover, the agriculture in India constitutionally under the control of states and increasing industrial lobbying for protection and farmer lobbying for subsidies at state level pose additional problem for agriculture growth in India. Thus, insignificant growth of efficiency change and technical regress in Indian agriculture calls advance attention for further decomposition of efficiency change and technical change component of Malmquist productivity index.

The decomposition of efficiency change into pure and scale components reveals that a slow growth to the tune of 0.1 percent per annum in pure efficiency change and 0.6 percent per annum in scale efficiency change has been observed (Table A.2) and thus supports the earlier finding of Pratt et. al (2009) that efficiency barely change over last three decades. However, the slow efficiency improvements in all the states throughout the period have two explanations; First throughout in 1980's to reform period, government intervention in the market resulted in deterioration in terms of trade (ratio of prices received to prices paid by the agricultural sector), touching their lowest point at 83.4 in 1986-87. Lower real procurement prices had a negative effect on the farmers' incentives to work efficiently. Second, the deterioration of land infrastructure particularly the existing water conservation systems, constrained the farmers from applying best production techniques. (Ahluwalia, 1991) However, gross fixed capital formation in agriculture at 1980 constant prices sharply declined to an average annual growth rate of 1 percent during 1980-1990 from corresponding growth rate of 5 percent in previous decade.

As in this paper we are interested to decompose the technical change component of Indian agriculture, theoretically technical change (TC) is divided into biased and magnitude components.

TC = Biased technical Change* Magnitude Component of Technical Change

Moreover, it has been also observed that biased component of technical change can be further bifurcated into an input biased technical change and an output biased technical change.

$$TC = \underbrace{\sqrt{\frac{D_0^t\left(x^{t+1}, y^{t+1}\right)}{D_0^{t+1}\left(x^{t+1}, y^{t+1}\right)} / \frac{D_0^t\left(x^{t+1}, y^t\right)}{D_0^{t+1}\left(x^{t+1}, y^t\right)}}}_{OBTECH} * \underbrace{\sqrt{\frac{D_0^t\left(x^{t+1}, y^t\right)}{D_0^{t+1}\left(x^{t+1}, y^t\right)} / \frac{D_0^t\left(x^t, y^t\right)}{D_0^{t+1}\left(x^t, y^t\right)}}}_{IBTECH} * \underbrace{\frac{D_0^t\left(x^t, y^t\right)}{D_0^{t+1}\left(x^t, y^t\right)}}_{MATECH}$$

Following Fare and Grosskopf (1996) and Fare et. al (1997), for the one output case as in our case, the technical change index can be decomposed into the product of magnitude index and an input biased index. (i.e. output biased component of technical change is equal to unity (OBTECH =1)) The measure of MATECH represents the effects of the parallel shift in isoquant i.e., Hicks neutral type of technical progress and IBTECH represents biases in input use caused by the change in the slope of isoquant map. The values of MATECH equal to technical change under the joint Hicks neutrality, when IBTECH and OBTECH are simultaneous equal to unity. i.e. (OBTECH = IBTECH = 1) Fare et. al (1997)

The results depicts under Table A.3 reveals that the major source of technical change in Indian agriculture is the presence of input bias. The results also show that the change in bias index is far from zero percent, which is not consistent with Hicks neutral technological change. Therefore, the assumption of Hicks neutrality is rejected though it cannot be tested statistically. The issue is important since under the traditional growth accounting framework the study of total factor productivity requires Hicks neutrality of technological change in order to represent the state of technology by a scalar (Solow, 1957). Further, it is evident from Table A.3 that in pre reforms period the state of Karnataka (1.7 percent) exhibits highest growth in technical change followed by Punjab (1.4 percent) whereas the states namely Assam, Madhya Pradesh, Maharashtra and Bihar have registered negative technical change to the tune of 0.7 to 0.8 percent in pre-reforms period. However, the results of post reforms period confirms the technical progress in states namely Bihar, Gujarat, Maharashtra, Orissa and West Bengal. Further, the state of Haryana, Bihar, Assam and Madhya Pradesh has registered highest growth in magnitude of technical change in entire period. The analysis related to pre-reforms period reveals that states namely Assam, Haryana and Madhya Pradesh have shown the positive growth in magnitude component of technical change. However, the states namely Andhra Pradesh, Assam, Rajasthan and West Bengal witnessed stagnation during the post reforms period. Moreover, the analysis also depicts that magnitude component of technical change in most of the years of entire study period has found to be close to unity, thus supports the finding of 100 percent of the technical regress during the entire study period has been contributed by Hicks non-neutral type of technical progress (i.e. IBTECH). Moreover, the presence of input bias was more than in pre-reform period than post-reforms period. Therefore, the priority would be given to expand the production scale to improve the productivity loss associated with the biased component of the technical change.

Recall from Table 3, if capital-labour ratio increases and IBTECH<1, it implies capital using technical bias and vice-versa. In the present study capital-labour ratio is found to be increasing at all India level (Table A.1) and state level, thus identified the presence of capital deepening technical progress in Indian agriculture. For example, that fewer labourers are required given output level, resulting from innovations of labour-saving agriculture technology by increasing the area farmed by the average worker. The impact of economic reforms pertaining to input biased technical change reveals that even though the input bias found to be decreased in post reforms period as compare to pre reforms period but the presence of IBTECH is still identified and thus reflects the labour saving or capital using technology of Indian agriculture.

5. Conclusion

The paper proposes a simple framework for the evaluation of productivity growth along with its sources of Indian agriculture. The analysis based on data envelopment analysis, reveals that the productivity growth of Indian agriculture is negative, therefore confirms that the entire output growth is contributed by input growth. The observed negative TFP growth in Indian agriculture at aggregate level is matter of serious concern in the light of the argument of policy planers that a minimum 4 percent per annum agriculture growth is required to sustain the aggregate growth of 8 percent per annum of Indian economy. However, given the negative productivity growth rate, it seems difficult to carry on high economic growth rate of Indian agriculture because TFP is important component of output growth under growth accounting framework.

In order to detect the cause of such a fragile nature of TFP growth, the results of the decomposition of productivity growth reveals that the efficiency change is positively contributing towards the growth of productivity whereas, the negative growth of technology restrict the potential productivity growth in Indian agriculture. The phenomenon of technical regress in Indian agriculture can also be supported on the ground that continuous falling public investments and government expenditure on research and development along with high input prices diversified the activities of farmers from high value crops to low risky and less input demanding crops and hence restrict the outward movement of frontier. Thus, insignificant growth of efficiency change and technical regress in Indian agriculture calls advance attention for further decomposition of efficiency change and technical change component of Malmquist productivity index.

The decomposition of efficiency change into pure and scale components reveal that a slow growth has been observed of pure efficiency change and scale efficiency change (Table A.2). The slow efficiency improvements in all the states throughout the period may have two explanations; *First* throughout in 1980's to reform period, government intervention in the market an production intensified which resulted in deterioration in terms of trade (ratio of prices received to prices paid by the agricultural sector), touching their lowest point at 83.4 in 1986-87. Lower real procurement prices had a negative effect on the farmers' incentives to work efficiently. *Second*, The deterioration of land infrastructure particularly the existing water conservation systems, constrained the farmers from applying best production techniques. However, gross fixed capital formation in agriculture at 1980 constant prices sharply declined to an average annual growth rate of 1 percent during 1980-1990 from corresponding growth rate of 5 percent in previous decade.

Further, the decomposition of technical change into biased and magnitude components reveal that the major source of technical change in Indian agriculture is presence of input bias, thus, confirms the presence of Hicks non-neutral technological change in Indian agriculture. Moreover, the magnitude component of technical change in most of the years of entire study period is found to be close to unity, therefore, supports the finding of 100 percent of the technical regress during the entire study period has been contributed by Hicks non-neutral type of technical progress (i.e. IBTECH). Hence, the priority would be given to expand the production scale to improve the productivity loss associated with the biased component of the technical regress. The impact of economic reforms pertaining to input biased technical change reveals that even though the input bias found to be decreased in post reforms period as compared to pre reforms period but the presence of IBTECH is still identified and thus reflects the labour saving or capital using technology in Indian agriculture.

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Appendices

Table A.1: Total Factor Productivity Growth in Indian Agriculture

Years	TFP	EFCH	PEFCH	SEFCH	TECH	IBTECH	MATECH	(K/L)
1972/73	0.8382	0.9570	0.9850	0.9780	0.8760	0.7965	1.1083	1.0609
1973/74	0.8517	0.8930	0.9890	0.9020	0.9540	0.8998	1.0839	1.0589
1974/75	0.8921	1.0520	1.0000	1.0550	0.8480	0.8144	1.0472	1.0753
1975/76	0.9365	0.9910	0.9930	1.0030	0.9450	0.9353	1.0294	1.0179
1976/77	0.9537	1.0000	0.9950	1.0040	0.9540	0.9331	1.0314	1.0969
1977/78	1.0388	1.0200	0.9830	1.0440	1.0180	1.0224	0.9993	1.0404
1978/79	0.9176	1.0040	1.0020	1.0030	0.9140	0.8936	1.0261	1.1362
1979/80	0.9737	1.0210	1.0460	0.9770	0.9540	0.9101	1.0533	1.1363
1980/81	1.0114	1.0780	1.0180	1.0610	0.9380	0.9437	0.9970	0.9667
1981/82	0.9799	1.0190	0.9940	1.0260	0.9620	0.9052	1.0673	1.0562
1982/83	0.7920	1.0170	1.0000	1.0150	0.7790	0.7425	1.0548	1.0420
1983/84	0.9418	1.0140	1.0100	1.0030	0.9290	0.9477	0.9867	1.0179
1984/85	0.9999	1.0000	1.0000	1.0010	1.0000	0.9868	1.0279	1.1224
1985/86	0.9822	0.9800	0.9890	0.9910	1.0020	1.0042	1.0053	1.0467
1986/87	1.0677	1.0300	1.0030	1.0280	1.0370	1.0229	1.0168	1.0253
1987/88	0.9190	0.9860	1.0070	0.9790	0.9320	0.8836	1.0593	1.0760
1988/89	0.9685	1.0410	1.0080	1.0330	0.9300	0.9584	0.9804	1.0553
1989/90	0.9491	0.9970	0.9940	1.0030	0.9520	0.9607	0.9956	1.0148
1990/91	0.9575	0.9820	0.9880	0.9920	0.9750	0.9513	1.0315	1.0422
1991/92	0.9943	0.9770	1.0050	0.9730	1.0180	1.0101	1.0113	1.0810
1992/93	1.1187	1.0680	1.0020	1.0670	1.0470	1.0796	0.9798	0.9560
1993/94	1.1185	1.0520	1.0330	1.0210	1.0630	1.0436	1.0233	1.0496
1994/95	0.8679	0.8970	0.9820	0.9130	0.9680	0.9727	0.9971	1.0510
1995/96	0.9971	1.0440	1.0140	1.0310	0.9550	0.9396	1.0181	0.9796
1996/97	1.0253	1.0290	0.9950	1.0350	0.9960	1.0061	0.9929	0.9923
1997/98	1.0590	1.0120	0.9940	1.0220	1.0460	1.0367	1.0116	1.0558
1998/99	1.0922	1.0140	1.0140	1.0010	1.0770	1.0718	1.0083	1.0223
1999/00	0.8930	0.9480	0.9740	0.9760	0.9420	0.9306	1.0162	1.0598
2000/01	1.0280	1.0340	1.0100	1.0240	0.9940	1.0036	0.9931	1.1003
2001/02	1.0681	1.0030	1.0100	0.9930	1.0650	1.0675	0.9994	1.0638
2002/03	0.8482	1.0450	0.9970	1.0480	0.8120	0.7948	1.0220	1.0329
2003/04	0.9462	0.9790	1.0130	0.9670	0.9670	0.9812	0.9895	1.0746
2004/05	1.0985	1.0250	0.9800	1.0460	1.0720	1.0850	0.9941	0.8701
Entire Period	0.9699	1.0060	1.0010	1.0060	0.9680	0.9518	1.0195	1.0434
Pre reforms	0.9459	1.0060	1.0010	1.0060	0.9510	0.9231	1.0301	1.0526
Post reforms	1.0081	1.0070	1.0020	1.0070	0.9970	0.9963	1.0034	1.0276
1991-1994 (Early reforms)	1.0194	0.9961	1.0053	0.9918	1.0234	1.0257	1.0027	1.0333
1995-2004 (Post WTO Period)	0.9892	1.0018	0.9984	1.0043	0.9875	0.9866	1.0038	1.0256

Note: The column K/L represents the ratio of $(K/L)^{t+1}$ to $(K/L)^{t}$. Source: Author's Calculations

Table A.2: Total Factor Productivity Growth and Overall Technical Efficiency Change in Indian Agriculture

State	TFP			EFCH			PEFCH				SEFCH		
	Entire	Pre Reforms	Post Reforms	Entire	Pre Reforms	Post Reforms	Entire	Pre Reforms	Post Reforms	Entire	Entire	Pre Reforms	Post Reforms
A.P.	0.967	0.939	1.006	1.007	1.007	1.007	1.002	0.998	1.009	1.011	1.016	1.001	0.970
Assam	0.944	0.908	0.994	1.010	1.005	1.019	1.000	1.000	1.000	1.01	1.005	1.019	0.951
Bihar	0.948	0.907	1.008	1.008	1.006	1.011	0.999	1.001	0.996	1.008	1.004	1.014	0.954
Gujarat	0.984	0.960	1.017	1.008	1.003	1.018	1.001	0.996	1.009	1.012	1.011	1.015	0.989
Haryana	0.973	0.953	1.000	1.008	1.008	1.006	1.003	1.000	1.008	1.007	1.011	1.001	0.977
Karnataka	1.006	1.003	1.010	1.005	1.007	1.001	1.000	1.000	1.000	1.005	1.007	1.001	1.010
M.P.	1.159	1.287	1.005	1.003	1.005	0.999	1.000	1.000	1.000	1.003	1.005	0.999	0.947
Maharashtra	0.932	0.895	0.984	1.009	1.012	1.005	1.002	1.003	0.999	1.008	1.008	1.008	0.936
Orissa	0.942	0.908	0.990	1.010	1.018	0.995	1.005	1.007	1.003	1.005	1.013	0.992	0.948
Punjab	1.008	1.003	1.014	1.003	0.994	1.018	1.000	1.000	1.000	1.003	0.994	1.018	1.011
Rajasthan	0.943	0.899	1.006	1.007	1.004	1.012	1.000	1.000	1.000	1.007	1.004	1.012	0.945
Tamil Naidu	0.963	0.948	0.985	1.004	1.004	1.003	1.000	1.000	1.000	1.004	1.004	1.003	0.968
U.P.	0.980	0.959	1.008	1.007	1.008	1.005	1.000	1.000	1.000	1.007	1.008	1.005	0.984
West Bengal	0.939	0.898	0.998	1.001	1.004	0.997	1.001	1.004	0.997	1.001	1.001	1.001	0.950
All India	**0.970**	**0.943**	**1.007**	**1.006**	**1.006**	**1.007**	**1.001**	**1.001**	**1.002**	**1.006**	**1.006**	**1.007**	**0.968**

Note: i) EFCH, PEFCH and SEFCH represents overall technical efficiency change, pure technical efficiency change and scale efficiency change respectively ii) TFP reflects the total factor productivity growth iii) All values are geometric means of states' score between 1971-2004.
Source: Author's Calculations

Table A.3: Technical Change and Input Bias in Indian Agriculture

State	TECH			MATECH			IBTECH		
	Entire	Pre Reforms	Post Reforms	Entire	Pre Reforms	Post Reforms	Entire	Pre Reforms	Post Reforms
Andhra Pradesh	0.970	0.956	0.998	1.006	1.011	1.000	0.966	0.937	1.006
Assam	0.951	0.923	0.999	1.044	1.075	1.001	0.923	0.855	1.016
Bihar	0.954	0.926	1.004	1.048	1.071	1.018	0.918	0.863	0.994
Gujarat	0.989	0.982	1.000	1.007	1.018	0.991	0.995	0.979	1.017
Haryana	0.977	0.966	0.996	1.049	1.061	1.032	0.944	0.922	0.973
Karnataka	1.010	1.017	0.998	1.014	1.019	1.007	1.000	1.003	0.996
Madhya Pradesh	0.947	0.918	0.999	1.044	1.072	1.007	0.912	0.849	0.997
Maharashtra	0.936	0.919	1.005	1.034	1.054	1.006	0.909	0.861	0.975
Orissa	0.948	0.914	1.005	1.033	1.026	1.042	0.923	0.886	0.973
Punjab	1.011	1.014	1.002	0.973	0.986	0.955	1.044	1.031	1.061
Rajasthan	0.945	0.921	0.991	1.021	1.036	1.001	0.932	0.882	1.000
Tamil Naidu	0.968	0.960	0.981	0.979	0.979	0.980	0.994	0.980	1.013
Uttar Pradesh	0.984	0.978	0.998	1.025	1.035	1.012	0.968	0.951	0.991
West Bengal	0.950	0.917	1.009	1.003	1.003	1.003	0.951	0.907	1.012
All India	**0.968**	**0.951**	**0.997**	**1.020**	**1.032**	**1.004**	**0.951**	**0.922**	**0.997**

Note: i) All values are geometric mean of states' score of entire period.
Source: Author's Calculations

Table A.4: Weights of Value of Output per Hectare Used to Drive Composite Index of Output

	A.P.	Assam	Bihar	Gujarat	Haryana	Karnataka	M. P.	Maharashtra	Orissa	Punjab	Rajasthan	T. N.	U.P.	W. B.
Paddy	0.212123	0.50	0.220386	N.A.	0.139085	0.285808	0.075684	N.A.	0.004115	0.340518	N.A.	0.341075	0.150889	0.50
Wheat	N.A.	N.A.	0.226781	N.A.	0.217589	N.A.	0.172399	N.A.	N.A.	0.306783	0.18873	N.A.	0.145718	N.A.
Jowar	0.155321	N.A.	N.A.	N.A.	N.A.	0.06532	0.129732	0.290078	N.A.	N.A.	0.125896	N.A.	N.A.	N.A.
Bajara	N.A.	N.A.	N.A.	0.358594	0.166412	N.A.	N.A.	N.A.	N.A.	N.A.	0.239781	N.A.	0.1433	N.A.
Maize	0.174335	N.A.	0.24164	N.A.	N.A.	N.A.	0.14124	N.A.	N.A.	N.A.	0.217822	N.A.	0.125503	N.A.
Moong	0.166205	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.496835	N.A.	N.A.	N.A.	N.A.	N.A.
Urad	0.166205	N.A.	N.A.	N.A.	N.A.	N.A.	0.08547	N.A.	N.A.	N.A.	N.A.	N.A.	0.086581	N.A.
Ground Nut	0.001508	N.A.	N.A.	0.354155	N.A.	0.102323	N.A.	0.311557	0.495674	N.A.	N.A.	0.192204	N.A.	N.A.
Cotton	0.122737	N.A.	N.A.	0.287251	0.049106	0.254369	0.15785	0.294546	N.A.	0.077772	N.A.	0.161852	N.A.	N.A.
Sugarcane	0.001469	N.A.	0.182746	N.A.	0.115133	N.A.	N.A.	0.022373	N.A.	0.274927	N.A.	0.30487	0.139732	N.A.
Jute	N.A.	0.50	0.128446	N.A.	N.A.	N.A.	N.A.	N.A.	0.003376	N.A.	N.A.	N.A.	N.A.	0.50
Gram	N.A.	N.A.	N.A.	N.A.	0.1041	N.A.	0.162373	N.A.	N.A.	N.A.	0.00885	N.A.	0.087694	N.A.
Mustard	N.A.	N.A.	N.A.	N.A.	0.208576	N.A.	N.A.	N.A.	N.A.	N.A.	0.218922	N.A.	0.120584	N.A.
Ragi	N.A.	N.A.	N.A.	N.A.	N.A.	0.241904	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Sunflower	N.A.	N.A.	N.A.	N.A.	N.A.	0.050277	N.A.	0.081446	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Arhar	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.075253	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Note: The values of weights are square of loadings of first Principal Component.

Source: Author's Calculations.

Table A.5: Weights of Value of Labour Use per Hectare Used to Drive Composite Index of Labour

	A.P.	Assam	Bihar	Gujarat	Haryana	Karnataka	M.P.	Maharashtra	Orissa	Punjab	Rajasthan	T. N.	U.P.	W. B.
Paddy	0.078689	0.50	0.032591	N.A	0.163308	0.11258	0.032371	N.A	0.42919	0.398415	N.A.	0.24807	0.02413	0.50
Wheat	N.A	N.A	0.339933	N.A	0.0889	N.A	0.252657	0.025278	N.A	0.410669	0.214954	N.A	0.16797	N.A
Jowar	0.112853	N.A	N.A	N.A	N.A	0.07430	0.08944	N.A	N.A	N.A	0.21062	N.A	N.A	N.A
Maize	0.007989	N.A	0.220508	N.A	N.A	N.A	0.089921	N.A	N.A	N.A	0.047658	N.A	0.08925	N.A
Bajra	N.A.	N.A	N.A	0.394669	N.A	N.A	N.A	N.A	N.A	N.A	0.382678	N.A	0.19060	N.A
Urad	0.153167	N.A	N.A	N.A	3.48E-05	N.A	0.099686	N.A	N.A	N.A	N.A	N.A	0.18182	N.A
Moong	0.110828	N.A	N.A	N.A	N.A	N.A	N.A	N.A	0.02423	N.A	N.A	N.A	N.A	N.A
Groundnut	0.033643	N.A	N.A	0.150376	N.A	0.14935	N.A	0.328714	0.42781	N.A	N.A	0.09211	N.A	N.A
Cotton	0.273005	N.A	N.A	0.454956	0.315267	0.20407	0.002912	0.272328	N.A	0.035676	N.A	0.25492	N.A	N.A
Sugarcane	0.229824	N.A	0.121654	N.A	0.269778	N.A	N.A	0.247205	N.A	0.155214	N.A	0.40488	0.00446	N.A
Jute	N.A.	0.50	0.285314	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A	0.50
Gram	N.A	N.A	N.A	N.A	0.009152	N.A	0.252657	N.A	N.A	N.A	0.041303	N.A	0.17242	N.A
Mustard	N.A	N.A	N.A	N.A	0.153561	N.A	N.A	N.A	0.11876	N.A	0.102786	N.A	0.16932	N.A
Ragi	N.A	N.A	N.A	N.A	N.A	0.15396	N.A	N.A	N.A	N.A	N.A	N.A	N.A	N.A
Sunflower	N.A	N.A	N.A	N.A	N.A	0.30572	N.A	0.126475	N.A	N.A	N.A	N.A	N.A	N.A
Arhar	N.A	N.A	N.A	N.A	N.A	N.A	0.209356	N.A	N.A	N.A	N.A	N.A	N.A	N.A

Note: The values of weights are square of loadings of first Principal Component.

Source: Author's Calculations.

Table A.6: Weights of Value of Machine Use per Hectare Used to Drive Composite Index of Capital

	A.P.	Assam	Bihar	Gujarat	Haryana	Karnataka	M.P.	Maharashtra	Orissa	Punjab	Rajasthan	T. N.	U.P.	W. B.
Paddy	0.186117	0.50	0.263628	N.A.	0.068236	0.219797	0.15674	N.A.	0.386131	0.086585	N.A.	0.279401	0.133968	0.50
Wheat	N.A.	N.A.	0.282988	N.A.	0.093517	N.A.	0.158857	N.A.	N.A.	0.340972	0.125242	N.A.	0.107928	N.A.
Jowar	0.110362	N.A.	N.A.	N.A.	N.A.	0.134187	0.157719	0.212881	N.A.	N.A.	0.135055	N.A.	N.A.	N.A.
Maize	0.06897	N.A.	0.13904	N.A.	N.A.	N.A.	0.140717	N.A.	N.A.	N.A.	0.165976	N.A.	0.052469	N.A.
Bajra	0	N.A.	N.A.	0.337278	0.19959	N.A.	0	N.A.	N.A.	N.A.	0.195572	N.A.	0.151193	N.A.
Urad	0.163114	N.A.	N.A.	N.A.	N.A.	N.A.	0.11793	N.A.	N.A.	N.A.	N.A.	N.A.	0.152819	N.A.
Moong	0.143311	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.354716	N.A.	0.193994	N.A.	N.A.	N.A.
Groundnut	0.177013	N.A.	N.A.	0.361624	0	0.185535	N.A.	0.164426	0.259093	N.A.	0.184163	0.233083	0.126163	N.A.
Cotton	0.000112	N.A.	N.A.	0.301099	0.167652	0.200362	0.05526	0.196162	N.A.	0.231472	N.A.	0.23388	N.A.	N.A.
Sugarcane	0.151001	N.A.	0.034368	N.A.	0.128811	0.106553	N.A.	0.21874	N.A.	0.340972	N.A.	0.253636	0.130574	N.A.
Jute	N.A.	0.50	0.279976	N.A.	0	N.A.	N.A.	N.A.	6.08E-05	N.A.	N.A.	N.A.	N.A.	0.50
Gram	N.A.	N.A.	N.A.	N.A.	0.153267	N.A.	0.166144	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Mustard	N.A.	N.A.	N.A.	N.A.	0.188927	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.144885	N.A.
Ragi	N.A.	N.A.	N.A.	N.A.	N.A.	0.153564	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Sunflower	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.20779	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.
Arhar	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	0.046632	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.

Note: The values of weights are square of loadings of first Principal Component.

Source: Author's Calculations.