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**TRENDS IN TOTAL FACTOR PRODUCTIVITY IN
INDIAN AGRICULTURE: STATE-LEVEL EVIDENCE
USING NON-PARAMETRIC SEQUENTIAL
MALMQUIST INDEX**

SHILPA CHAUDHARY

Email: shilpa@econdse.org
**Delhi School of Economics
University of Delhi**

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Centre for Development Economics
Department of Economics, Delhi School of Economics

Trends in Total Factor Productivity in Indian Agriculture: State-level Evidence using non-parametric Sequential Malmquist Index

Shilpa Chaudhary

Abstract

Recognizing the critical role of agricultural sector in the overall growth as well as development performance, this study estimates total factor productivity (TFP) in Indian agriculture at state-level. Using Index of Agricultural Production as the measure of output, changes in TFP are estimated using non-parametric Sequential Malmquist TFP index. The TFP change is decomposed into efficiency change and technical change. It is found that productivity improvements are marked in very few states, and so is technical change. The improvements in efficiency are observed to be low for most of the states and efficiency decline is observed in several states implying huge gains in production possible even with existing technology. In order to achieve higher productivity, it is essential to increase efficiency levels as well as achieve a more even spread of new technology.

Section I: Introduction

A rise in production can be attributed to a growth in inputs or growth in total factor productivity. The level of Total Factor Productivity (TFP) can be measured by dividing total output by total inputs. When all inputs in the production process are accounted for, TFP growth can be thought of as the amount of growth in real output that is not explained by growth in inputs.

Productivity growth encompasses changes in efficiency as well as changes in the best practice. A firm is fully technically efficient if it is operating on the production frontier (i.e. it is achieving best practice), the production frontier being defined for a reference time period with reference to a particular set of firms. A rise in efficiency implies either more output is produced with the same amount of inputs or that less inputs are required to produce the same level of output. Equally, the outward shift of a production frontier implies productivity growth.

There are several studies which point out decline in agricultural productivity in developing countries even in the years well-known for success of Green Revolution. The modified Malmquist TFP index- using Sequential/ Long memory technology, as proposed by Forstner and Isaksson (2002) and Nin et al (2003), attempts to rectify the biases in computation of productivity growth arising from non-neutral technical change. This study uses non-parametric Sequential Malmquist TFP Index to estimate changes in total factor productivity in Indian agriculture at state-level.

Section II: Literature Review

Most of the studies that estimate agricultural total factor productivity in developing countries¹ have found TFP to be declining even in the years which are well known for green revolution success arising primarily due to adoption of new and improved varieties of wheat and rice.

Kawagoe et al. (1985), using data for 1960, 1970 and 1980 in 21 developed countries and 22 less developed countries, estimate cross-country production functions for 1970 and 1980. They find technological regression during both decades for the less developed countries, but technological progress in the developed countries. Kawagoe and Hayami (1985) use an indirect production function and find similar results in that data set. Fulginiti and Perrin (1993) estimate technical progress for LDCs for the period 1961-1985 using Cobb-Douglas production specification. The study reports technological regression for 14 of the 18 countries. It is possible, as suggested by the authors that interferences with the agricultural sector such as price policies had a depressing effect on incentives so as to stifle potential productivity gains. Fulginiti and Perrin (1998) use a parametric meta-production function and a non-parametric Malmquist index to examine the performance of the agricultural sectors in a set of 18 LDCs and find productivity regress in many of them.

Trueblood (1996) uses non-parametric Malmquist index and also estimates Cobb-Douglas production function for 117 countries. The study also finds negative productivity growth in a significant number of developing countries. Arnade (1998) estimates agricultural productivity indices using non-parametric Malmquist index approach for 70 countries during the years 1961-1993. It is found that thirty six out of forty seven developing countries in the sample show negative rates of technical change. Kudaligama and Yanagida (2000), using deterministic and stochastic frontiers for 43 developed and developing countries over 1960, 1970 and 1980, indicate agricultural productivity for developing countries on a per farm basis deteriorated over the time period under consideration.

Nin et al (2003) estimate TFP growth for 20 countries during 1961-1994 using non parametric Malmquist TFP index with an alternative definition of technology-sequential technology - and find that the earlier results reverse, and most of the developing countries experience productivity growth.

Coelli et al (2003) estimate TFP for Bangladesh crop agriculture for the period 1961-1992 using stochastic frontier approach and find a decline in TFP over the period (mean TFP change = 0.9537). Rahman (2004) applies sequential Malmquist index approach to same dataset and finds TFP rising at the rate of 0.9% p.a and this growth is primarily led by those regions which have experienced high levels of Green revolution technology. Technical progress is found to be growing at 1.9% p.a that offsets declining efficiency at 1% p.a.

¹ The literature of getting technological regression in developing countries, even in those which are well-known for technical progress is quite vast for GDP but relatively less for agricultural TFP

Alene (2009) estimates TFP in African agriculture for the period 1970-2004 using both contemporaneous and sequential Malmquist TFP index. The study finds that while the conventional Malmquist method estimates aggregate TFP growth to be a modest 0.3% p.a (most of the stagnation of TFP growth is explained by technical regress), using sequential Malmquist approach the TFP is found to be rising at 1.8% p.a.

There are a number of studies on the measurement of productivity that have been carried out for India as well. These studies pertain to agriculture sector and crop-specific analysis. There are few estimates available of TFP changes at state-level. A notable study in this regard is Fan, Hazell and Thorat (1998) which estimates TFP for agriculture at state-level using Tornqvist-Theil index for the period 1970-1994. The study finds that total factor productivity for India grew at an average annual rate of 0.69 percent between 1970 and 1995. In the 1970s, total factor productivity improved rapidly, growing at 1.44 percent per annum, grew faster in the 1980s at 1.99 percent per annum. But since 1990, total factor productivity growth in Indian agriculture has declined by 0.59 percent per annum. The study also reports state-level estimates- for the whole period 1970 to 1994, the states with TFP growth rate in the range 0-1 percent per annum are Andhra Pradesh, Karnataka, Uttar Pradesh, Himachal Pradesh and Kerala; with TFP growth rate greater than one are Punjab, Bihar, Orissa, Maharashtra, West Bengal and J&K. The states with negative TFP growth are Haryana, Madhya Pradesh, Gujarat, Assam and Rajasthan.

Kumar and Rosegrant (1994) estimate TFP growth for rice. They find that the TFP index has risen by around 1.85 per cent annually in the southern region (Andhra Pradesh, Tamil Nadu, Karnataka and Kerala), 0.76 per cent in the northern region (Haryana, Punjab and Uttar Pradesh) and 0.36 per cent in the eastern region (Assam, Bihar, Orissa and West Bengal). In the western region (Gujarat, Maharashtra, Madhya Pradesh and Rajasthan), the annual TFP growth was found to be negative but insignificant.

Chand et al (2011) estimate crop-level TFP for the period 1986-2005 using Divisia-Tornqvist index. They find highest TFP growth for wheat crop. Except wheat and groundnut, TFP growth during 1986-95 is found to be lower than 1975-1985 in all crops and for several crops during 1996-2005. The percentage of cropped area for different states is distributed as per TFP growth rates and they find that the states of Punjab, Gujarat and Andhra Pradesh have highest TFP growth with 90% or more of cropped area having TFP growth more than 1%. Tamil Nadu, Haryana, Uttar Pradesh, Maharashtra have cropped area distributed across all TFP growth categories². The states of Madhya Pradesh, West Bengal, Bihar, Orissa, Karnataka, Kerala and Himachal Pradesh have larger percentage of cropped area reporting negative or stagnant TFP growth.

² The TFP growth categories are formulated as follows: negative growth (less than zero), stagnant growth (0- 0.5%), low growth (0.5-1%), moderate (1-2%) and high (greater than 2%).

Turning to studies on crop sector and crop-specific studies, Rosegrant and Evenson (1992) use Tornqvist-Theil index to estimate TFP change for Indian crop sector. They find rate of growth of TFP to be 1% for the entire period 1957-1985, 0.81% for the period 1957-1965, 1.22% during 1965-1975 and 0.98% during 1975-1985.

Mukherjee and Kuroda (2001) use Tornqvist-Theil methodology to construct the TFP index for Indian agriculture in fourteen states from 1973 to 1993. They find TFP index to be 1.73 for 1973-79, 2.51 for 1980-89, 1.34 for 1990-1993 and 2.19 for entire period 1973-2003. Bosworth and Collins (2007) use growth accounting approach and estimate TFP growth in primary sector for India to be 0.8% during 1978-2004, 1% for the period 1978-1993 and 0.5% for the period 1993-2004.

Murgai (1999) uses Tornqvist-Theil Index to estimate TFP growth in Punjab at district level during 1960-1993. TFP growth averaged 1.9 percent from 1960 to 1993. Productivity growth in Punjab is found to be lowest during the green revolution years, even as farmers moved from traditional varieties of wheat and rice to modern hybrid seed varieties and the agricultural sector experienced high growth rates in production. The study attributes most yield improvements to rapid factor accumulation, particularly that of fertilizers and capital. Contrary to widespread belief, the contribution of productivity growth to economic growth is found to be small.

Rao (2005) uses Tornqvist-Theil index to estimate TFP changes for Andhra Pradesh across different crops for the period 1980-81 to 1999-2000. The study finds TFP growth rate for all the crops to be 0.23% in the pre-1990s period and -0.17% during the post-reform period. The corresponding percentages are found to be -0.02 and 0.91 for foodgrains and 0.41 and -1.06 for the non-foodgrains.

Kumar and Mittal (2006) estimate TFP growth across different states for paddy and wheat. They find TFP of paddy has started showing deceleration in Haryana and Punjab but TFP of wheat is still growing in these two Green Revolution states. About 60 per cent of the area under coarse cereals is facing stagnated TFP. Similarly, the productivity gains which occurred for pulses and sugarcane during the early years of Green Revolution, have now exhausted their potential.

Bhushan (2005) uses Data Envelopment Analysis to estimate Malmquist TFP index for major wheat producing states in India- Punjab, Haryana, Madhya Pradesh, Uttar Pradesh and Rajasthan. He finds TFP growth rate to be highest in Punjab and Haryana which is attributed to technical progress in these two states. Rajasthan (with no efficiency change) and Uttar Pradesh (with improvement in efficiency and negative growth in technological progress) have positive TFP growth rate while Madhya Pradesh (no change in efficiency and negative growth of technical progress) is reported to record negative TFP growth rate. As compared to 1980s, mean growth of TFP is found to be higher in 1990s and the primary source of TFP growth is technical progress and not efficiency improvements.

Section III: Methodology

This section begins by briefly describing the Malmquist TFP index and thereafter discusses the modified version of the index by using a different method to construct production frontier.

Let the set theoretic representation of a production function that involves multiple outputs and inputs technology be described as the technology set S . Let \mathbf{x} and \mathbf{y} denote an $N*1$ input vector of non-negative real numbers and a non-negative $M*1$ output vector, respectively. The technology set is then defined as:

$$S=\{(\mathbf{x},\mathbf{y}): \mathbf{x} \text{ can produce } \mathbf{y}\} \quad (1)$$

This set consists of all input-output vectors (\mathbf{x},\mathbf{y}) such that \mathbf{x} can produce \mathbf{y} .

The piece-wise linear convex hull approach to estimate frontier was proposed by Farrell (1957) but the application of this methodology increased only after the term Data Envelopment Analysis was coined by Charnes, Cooper and Thodes (1978). Data Envelopment Analysis (DEA) is a non-parametric method of frontier estimation that makes use of linear programming. The approach constructs a “piece-wise surface (or frontier) over the data” (Coelli et al, 2005:162) such that the constructed frontier envelops all given data points, that is, all observed data points lie on or below the production frontier. The benchmark technology is hence constructed from among the *observed* input-output bundles of various production entities. “Efficiency measures are then calculated relative to this surface.” (Coelli et al 2005:162)

A major advantage in the use of DEA in measuring productivity growth is that this method does not require any price data. This is a distinct advantage, because in general, agricultural input price data are seldom available and such prices could be distorted due to government intervention³. The DEA seems to be a much more powerful tool for measurement of productivity since it also makes the least number of restrictive assumptions (no requirement of functional form of production function / distribution form of inefficiency) and at the same time permits decomposition of TFP change into two components of efficiency change and technical change that would help in gaining insights into the sources of growth of TFP. However, the disadvantage of DEA is that it does not account for noise (all noise is grouped into inefficiency) and the usual econometric tests of hypotheses and significance cannot be carried out.

DEA uses Distance Functions that allow us to describe a multi-input, multi-output production technology without any specification of a behavioural objective (such as

³ Most of the literature mentions about the price distortions only in developing countries because of government intervention. However, this is true even for developed countries where, in fact, the quantitative levels of support by the government to the farmers are extremely high as compared to those provided by governments of developing countries. The deadlock in WTO over the issue of opening up agricultural markets and reducing government support is an evidence in point here. Hence the problem of obtaining reliable/ undistorted price data for agricultural sector is true for both developed as well as developing countries.

cost-minimization or profit-maximization). The concept of distance function is closely associated with production frontiers. Distance functions can be output-oriented or input-oriented. An output distance function considers the maximum proportional expansion of the output vector corresponding to a given input vector. It measures the distance of a firm from its production frontier- how close a particular level of output is to the maximum attainable level of output that could be obtained from the same level of inputs if production is technically efficient. Fare, Grosskopf, Norris and Zhang (1994) define an output distance function at time t as

$$D_o^t(\mathbf{x}^t, \mathbf{y}^t) = \inf\{\theta : (\mathbf{x}^t, \mathbf{y}^t / \theta) \in \mathbf{S}^t\} = (\sup\{\theta : (\mathbf{x}^t, \theta \mathbf{y}^t) \in \mathbf{S}^t\})^{-1} \quad (2)$$

Distance function is defined as the inverse of the maximum proportional increase in the output vector \mathbf{y}^t , given the set of inputs \mathbf{x}^t and production technology \mathbf{S}^t . The distance so computed is equivalent to the reciprocal of Farrell's (1957) measure of technical efficiency⁴. The superscript t associated with D refers to which period's production frontier is used as reference technology. The calculation of distance functions and how they can be used to give insights about efficiency change and technical change is illustrated diagrammatically in Figure 1.

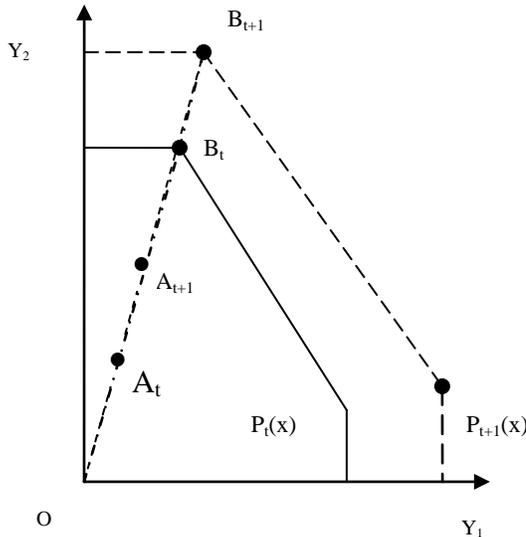


Figure 1: Production possibility set for period t and $t+1$
Source: Nin, Arndt and Preckel 2003:399

In Figure 1, production possibility sets are depicted for periods t and $t+1$. Firm B is lying on the frontier in both the time periods, implying it is fully technically efficient. Firm A lies inside the production frontier. For firm A, the distance from the

⁴ This is distinct from Koopmans measure of technical efficiency- a technically inefficient producer can produce the same quantity of output using less of atleast one of the inputs. This is more stringent measure of efficiency as compared to Farrell's measure which looks at proportional (radial) expansion or contraction of inputs/ outputs.

production point in time period t to the frontier in time period t , that is, $D_o^t(x_t, y_t)$ is given by OA_t/OB_t . This ratio is less than one implying the firm is inefficient. In case of firm B, the distance from its production point to the frontier shall be equal to one as it lies on the frontier. Firm A's distance of its production point from the frontier in time period $t+1$, $D_o^{t+1}(x_{t+1}, y_{t+1})$, is given by OA_{t+1}/OB_{t+1} . The comparison of these two distance functions tells about the performance of firm A on efficiency front. If firm A has become more efficient in time period $t+1$ than it was in time period t , then its production point in $t+1$ would be closer to the same period frontier than in the preceding period. In other words, the distance computed from $D_o^{t+1}(x_{t+1}, y_{t+1})$ would be greater than $D_o^t(x_t, y_t)$.

The above distances are calculated from same period's production frontier. However, the distances can also be computed using some other period's production frontier / technology. For example, for firm A, distance of its production point in time period t can be calculated with respect to frontier of time period $t+1$. This distance, $D_o^{t+1}(x_t, y_t)$ is given by OA_t/OB_{t+1} . Similarly, the distance of firm A's production point in time period $t+1$ can be computed using time period t 's frontier as reference technology. This distance, $D_o^t(x_{t+1}, y_{t+1})$, is given by OA_{t+1}/OB_t . A comparison of these mixed-period distance functions can tell us about whether or not technical change has taken place. If what is produced in time period $t+1$ could not have been produced in time period t , then the distance $D_o^t(x_{t+1}, y_{t+1})$ would be greater than one. Similarly, if the distance computed of period t 's production point from period $t+1$'s frontier exceeds that from period t 's frontier, that is $D_o^{t+1}(x_t, y_t) > D_o^t(x_t, y_t)$, then it implies an outward shift of production frontier in time period $t+1$.

Malmquist TFP Index

The Malmquist TFP index was first introduced by Caves, Christensen and Diewert (1982). They defined the TFP index using Malmquist input and output distance functions, and thus the resulting index came to be known as the Malmquist TFP index. The period t Malmquist productivity index is given by

$$M^t = \frac{D_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^t(\mathbf{x}^t, \mathbf{y}^t)} \quad (3)$$

i.e., they define their productivity index as the ratio of two output distance functions taking technology at time t as the reference technology. Instead of using period t 's technology as the reference technology it is possible to construct output distance functions based on period $(t+1)$'s technology and thus another Malmquist productivity index can be laid down as:

$$M^{t+1} = \frac{D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)} \quad (4)$$

Färe et al (1994) attempt to remove the arbitrariness in the choice of benchmark technology by specifying their Malmquist productivity change index as the geometric mean of the two-period indices, that is,

$$M_o(\mathbf{x}^{t+1}, \mathbf{y}^{t+1}, \mathbf{x}^t, \mathbf{y}^t) = \left[\left(\frac{D_o^t(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^t(\mathbf{x}^t, \mathbf{y}^t)} \right) \left(\frac{D_o^{t+1}(\mathbf{x}^{t+1}, \mathbf{y}^{t+1})}{D_o^{t+1}(\mathbf{x}^t, \mathbf{y}^t)} \right) \right]^{\frac{1}{2}} \quad (5)$$

Using simple arithmetic manipulation, the equation (5) can be written as the product of two distinct components- technical change and efficiency change (Färe et al (1994)).

$$Mo(x^{t+1}, y^{t+1}, x^t, y^t) = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})} \right) \left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)} \right) \right]^{\frac{1}{2}} \quad (6)$$

$$\text{where Efficiency change} = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \quad (7)$$

$$\text{Technical change} = \left[\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})} \right) \left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)} \right) \right] \quad (8)$$

Hence the Malmquist productivity index is simply the product of the change in relative efficiency that occurred between periods t and $t+1$, and the change in technology that occurred between periods t and $t+1$. A value of Malmquist TFP index equal to one implies there has been no change in total factor productivity across the two time periods, greater than one implies a rise / improvement in TFP and a value less than one is interpreted as a regress in TFP. A similar interpretation applies to the two components as well.

The Sequential Malmquist TFP Index

The first to question technical regress in a DEA framework were Tulkens and Eeckaut (1995). It is useful to point out Fulginiti and Perrin (1998) who mention that “it is also possible that the methods and data previously used have inaccurately portrayed the LDCs’ agricultural sectors as regressing in productivity..... two of these three frontier countries, Argentina and Korea, experienced declines in productivity during 1961-1985.....The Malmquist index indicates that, productivity in frontier-establishing countries (Argentina and Korea) was declining, which resulted in a measured regression of technology (negative technological change) and a measured improvement in technical efficiency among most of the other countries”.⁵ The

⁵ Forstner et al (2001) compute Malmquist TFP index using Data Envelopment Analysis to estimate productivity change at an aggregate level (GDP) over the period 1970-1992 for 32 Least Developed

problem in the technique of Malmquist index was, thus, laid down and the approach was modified by Forstner et al (2002) and Nin et al (2003) by dis-allowing technical regress.

Under standard DEA method, the production units can “*forget*” about production techniques used in the past. Such memory loss results in erroneous measurement of technological change and efficiency change. Forstner and Isaksson (2002:14) mention that “as a consequence, a country appears as performing exceptionally well in technical efficiency without actually having improved at all. This bias occurs when the country is located in a region where the world technology frontier is receding”. They propose an amendment to Data Envelopment Analysis called Long-Memory DEA (LMDEA) that imposes infinite technological memory.

Nin et al (2003) argue that technical regression is the combined consequence of biased technical change (frontier shrinks in atleast one input or output direction) and the definition of technology used to estimate the Malmquist index. They propose an alternative method of constructing the frontier of the production set - sequential production set - as against a contemporaneous production set. Since the production set under contemporaneous production technology takes into account the information about that particular time period only, successive production sets so constructed are independent of each other. The sequential production set, on the other hand, assumes that there is a certain form of dependence between the production sets across time. This dependence stems from the assumption that “production units can always do what they did before in the production process” (Nin et al 2003:407). Thus, the construction of the frontier in a particular time period will make use of information on input-output bundles for all the time periods up to that time period. The concept of sequential-technology frontier is similar to what Ahmad (1966) defines as the innovation possibility frontier, the envelope of all known or potentially discoverable technologies at period t .

In case of non-neutral technical change (in the Hicksian sense), the use of one or more inputs declines and that of others may be growing. The use of contemporaneous technology would then result in intersecting production frontiers. As an alternative, the Sequential technology prevents any segment of the technology frontier from receding. In the words of Forstner and Isaksson (2002:2), “Once a production technique becomes available and used, it is not erased from memory in successive time periods and remains, at least, potentially utilizable”.

The use of sequential technology might be necessitated even under Hicks-neutral technical change conditions. For example, if a natural calamity occurs in a *frontier* production unit, and usage of some inputs declines in that particular time period, the

Countries. They find an overall decline in total factor productivity (TFP), pointing to technology as a major problem area in the growth of these countries. The study, however acknowledges that behind such decline, there seems to be ‘best-practice regress’.

production frontiers of the two successive time periods can turn out to be intersecting. The biases discussed in context of non-neutral technical change would then apply.

The Sequential or Long-memory Malmquist TFP index seeks to rectify the two kinds of biases when contemporaneous technology is used under such circumstances. One, the estimated change in technical efficiency will be biased for the non-frontier production unit. This bias arises because in at least one of its segments the technology frontier is receding towards some non-frontier units. Such a firm will have moved closer to the frontier which would be reported as an increase in technical efficiency. Two, the problem arises for the frontier firm that experiences non-neutral technical change. The comparison of its two production points can result in reporting a *decline* in productivity for this firm.

This is shown diagrammatically in Figure 2. Part (a) depicts a situation where there is a simple outward shift of the production possibility set. In this case, Malmquist indices, as defined by equations (3) and (4) are $M_o^t = (OB_{t+1}/OB_t)/(OB_t/OB_t) = (OB_{t+1}/OB_t) / 1 = M_o^{t+1} = 1/(OB_t/OB_{t+1}) > 1$. However in case of biased technical change, the measures of productivity growth obtained by the two indices would turn out to be different. This is illustrated in Figure 2(b) where production of the frontier country B is not expanding along the same ray through the origin. The t-period based Malmquist index is estimated as $M_o^t = (OB_{t+1}/OE)/1 > 1$, that is, productivity in country B has risen due to technical progress. However, when productivity growth is estimated using t+1 period technology, it is estimated as $M_{t+1} = 1/(OB_t/OD) < 1$, that is, it indicates a decline in productivity in this country because of technical regress. A geometric mean of these two shall give Färe Malmquist TFP index that could turn out to be less than one and report productivity regress for the firm B.

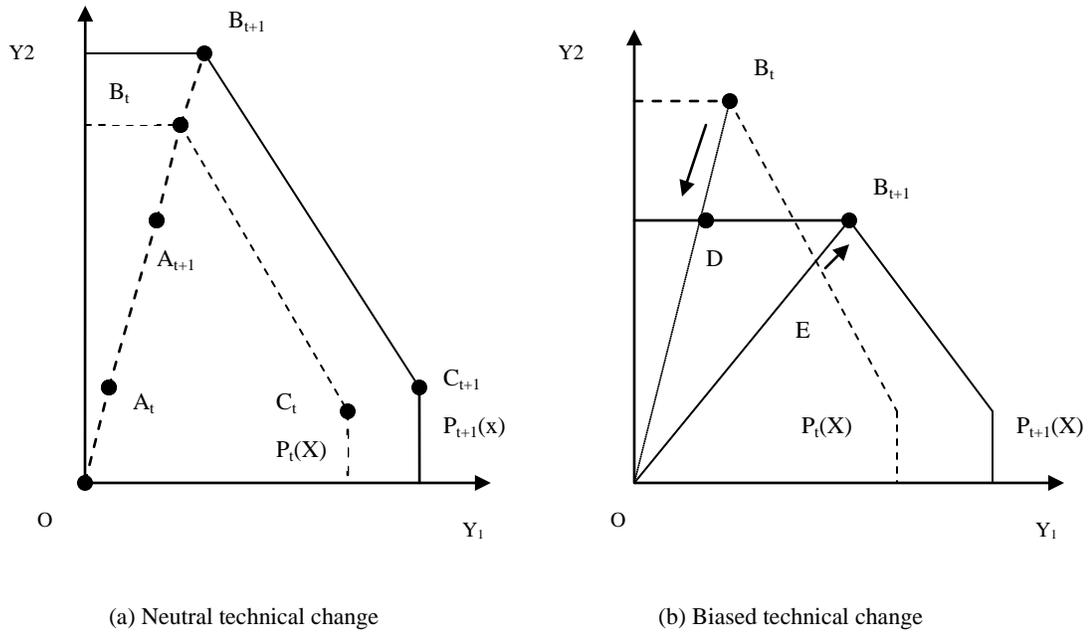


Figure 2: Output Possibility Set, periods t and t+1
 (Source: Nin et al, pp 400-401)

The sequential production set can be stated as follows:

$$P^{1,t}(x) = \bigcup_{j=1}^{t+1} P^{1,j}(x), \quad (9)$$

That is, the input-output mix used in previous years remains available and is part of technology in period t.

Figure 3 shows the shift in frontier with biased technical change assuming sequential technology (as against production frontier shifting inside in one of the ordinates in Figure 2b).

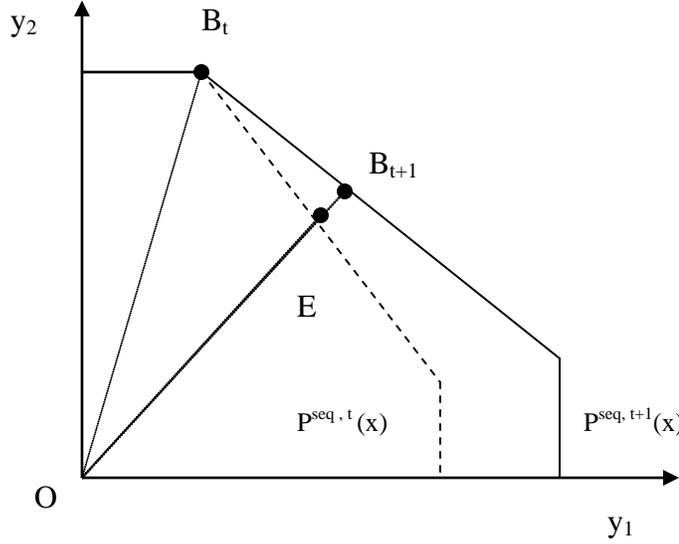


Figure 3: Output Possibility Set using Sequential technology (Source: Nin et al, pp 408)

A move from B_t to B_{t+1} is considered as technical progress under Sequential technology whereas under contemporaneous technology, it *can be* categorized as technical regress (that is, if $D^t(x_{t+1}, y_{t+1}) < D^{t+1}_o(x_t, y_t)$ or $OB_{t+1}/OE < OB_t/OD$ in Figure 2(b)).

It is to be noted that even though sequential technology rules out the possibility of technical regression, it does allow negative productivity growth through the route of decline in efficiency component.

Using the sequential DEA approach, the definition of the output distance function for each time period t has to be modified as follows:

$$d^t(x^t, y^t) = \inf \left\{ \theta : (y^t / \theta) \in P_t^{seq}(x) \right\}. \quad (10)$$

This distance function still represents the smallest factor, θ , by which an output vector y^t is deflated so that it can be produced with a given input vector x^t under period t 's technology. However, the technology described now is sequential/ long memory instead of contemporaneous/ short memory since the production sets of all time periods upto time period t are taken into account. The linear programming used to compute the distance functions is described in Appendix 1.

Section IV: Data

This section describes the output and input data used to estimate productivity changes in agriculture for the years 1983-1984 to 2005-06. The study focuses on crop

production. It uses Index of Agricultural Production that presently covers 42 crops accounting for nearly 96% of total gross cropped area in the country. The data is available for 13 major states- Andhra Pradesh, Assam, Gujarat, Haryana, Karnataka, Madhya Pradesh, Maharashtra, Orissa, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh, West Bengal- for the time period 1980s onwards. The data on Index of Agricultural Production is, however, very scanty for two states- Bihar and Kerala and hence Net State Domestic Product from agriculture has been used as an alternative output measure, as a proxy for Index of Agricultural Production for these two states.

There are six inputs taken. One, land as an input used is taken as Gross Cropped area. There is no distinction made on the quality of land, that is, land input is assumed to be homogenous. Two, water input is included through both rainfall (in millimeters per annum) and irrigation water as proxied by Gross area irrigated (in thousand hectares). Three, the fertilizer input is measured as total consumption of fertilizers of all three kinds- nitrogenous, phosphate and potassium (in million tonnes). Four, number of tractors are used as a proxy for machinery used in agriculture. The data on agricultural machinery is collected in Machinery Census conducted on quinquennial basis. The Machinery Censuses that have been conducted so far are in the years 1966, 1972, 1977, 1982, 1987, 1992, 1997 and 2003. The data for the various time-periods has been interpolated using census results. Five, livestock input is taken as total number of draught animals. Like machinery, the data on livestock is also collected in quinquennial census that have been conducted for the years 1966, 1972, 1977, 1982, 1987, 1992, 1997, 2003 and 2008. The data for the various time-periods has been interpolated using census results.

Lastly, the concept of labour used is number of persons engaged in agriculture. The estimates of workforce in agriculture are not available on an annual basis. There are two sources of estimates of workforce in different sectors – Population Census and surveys conducted by the National Sample Survey Organization. The Census figures on number of persons engaged as ‘Cultivators and Agricultural labourers’ are available only for the Census years- 1971, 1981, 1991 and 2001. In this case, the figures for workforce need to be interpolated for the remaining years. In order to avoid this large-scale interpolation, the study uses NSSO surveys for estimating the labour input⁶.

⁶ The quinquennial surveys on consumer expenditure and employment-unemployment were taken up in 27th Round (1972-73), 32nd Round (1977-78), 38th Round (1983), 43rd Round (1987-88), 50th Round (1993-94), 55th Round (1999-2000) and 61st Round (2005-6). From 42nd Round onwards, NSSO decided to canvass a slightly pruned schedule 1.0 in every round with a reduced sample of only two households per sample village/ block in order to derive an annual series on consumer expenditure. From 45th Round, it was decided to extend the scope of the annual survey to cover employment-unemployment as well so that an annual time series on employment and unemployment is available from 1989-90 onwards. The labour figures have been interpolated for the years 1984-85 to 1986-87 and 1988-1989.

Section V: Results

The Malmquist TFP index is not based on specific assumptions about the returns-to-scale properties of the production technologies. All the distances can be computed whether the technology exhibits variable returns to scale or constant returns to scale. However, Grifell-Tatje and Lovell (1995) use a simple one-input one-output example to illustrate that the Malmquist TFP index may not correctly measure TFP changes under variable returns to scale technology.

Most of the studies adopt the constant returns to scale frontier as a benchmarking technology. There are several studies that find constant returns to scale in developing countries and increasing returns to scale in developed countries- Hayami and Ruttan (1985), Khaldi (1975), Lopez (1980), Wan and Cheng (2001), Alcanatara and Prato (1973). Goyal and Suhag (2003) find for Haryana state of India for the years 1996-97 to 1998-99 that wheat cultivation in the state experienced constant returns to scale, as the sum of input elasticities (in the Cobb-Douglas production function) was 1.01.

This section presents TFP indices computed assuming constant returns to scale. There are four sets of TFP indices estimated - one, using Index of Agricultural Production data for thirteen states (excluding Bihar and Kerala) computed on the basis of contemporaneous technology⁷; two, using Index of Agricultural Production data for thirteen states (excluding Bihar and Kerala) computed on the basis of sequential technology⁸; three, using Index of Agricultural Production data for thirteen states and Net state domestic product from agriculture as a proxy for output for Bihar and Kerala⁹ computed on the basis of contemporaneous technology (for fifteen states) and four, using Index of Agricultural Production data for thirteen states and Net state domestic product from agriculture proxied for Bihar and Kerala computed on the basis of sequential technology.

All the above four sets of annual Malmquist TFP indices and their two components of Technical Efficiency Change and Technical Change are presented in Appendix 2. This section discusses at length the Malmquist TFP indices using sequential technology. Several studies on Malmquist TFP index have discussed only the direction of TFP index - whether TFP is declining or increasing or no change (TFP index less than 1, greater than 1 or equal to 1 respectively). The present study attempts to take into account the magnitude of the index as well. The TFP changes are categorized into negative growth rate, growth rate in the range 0-1 (marginal), 1-2 (small), 2-5 (medium) and more than 5 percent per annum (large). The trends in productivity growth are analyzed for the entire time-period 1983-84 to 2005-06 and for the sub-periods- 1983-84 to 1996-97 and 1997-1998 to 2005-6¹⁰.

⁷ The software used is Tim Coelli's DEAP version 2.1.

⁸ The software used is MINOS solver of GAMS.

⁹ The correlation between Index of agricultural production and net state domestic product from agriculture for Bihar and Kerala for the years for which Index of Agricultural production data is available is computed as 0.41 and 0.63.

¹⁰ Balakrishnan (2010) considers agricultural output data series from 1950-51 to 2003-4 and finds one structural break at the year 1964-65. Since there is no structural break since 1964-65, the periodization

V.1 TFP Performance (including Bihar and Kerala)

The productivity performance for fifteen states - using the measure of output as index of agricultural production for thirteen states and net state domestic product from agriculture for Bihar and Kerala – is discussed first. TFP growth rate is estimated to be 3.74%¹¹ during the first sub-period 1983-84 to 1996-97 and then declines to 2.99% during 1997-98 to 2005-6; the average TFP growth being 3.4% per annum for the entire time period.

For the overall time period 1983-84 to 2005-6, it is found that all states except Orissa exhibit improvement in productivity. There are ‘large’ productivity gains occurring in Haryana, Kerala, Punjab, and Tamil Nadu. While the states of Assam and West Bengal exhibit “medium” improvements in TFP, the states of Andhra Pradesh, Bihar, Karnataka, Maharashtra, Rajasthan and Uttar Pradesh exhibit ‘small’ productivity improvements. Gujarat and Madhya Pradesh experience “marginal” productivity gains (Table 1A and 1B).

Table 1A: Total Factor Productivity Growth (Percentage Per annum)

	1983-84 to 1996-97	1997-98 to 2005-6	1983-84 to 2005-6
AP	1.33	2.23	1.69
ASS	1.84	8.58	4.54
BIH	3.08	-0.84	1.46
GUJ	2.93	-2.93	0.49
HAR	8.36	8.34	8.35
KAR	2.99	-0.40	1.59
KER	12.56	8.11	10.72
MAHA	3.71	-2.44	1.15
MP	0.45	0.90	0.63
ORR	-2.33	2.15	-0.52
PUN	8.00	14.64	10.67
RAJ	1.37	2.71	1.92
TN	6.82	3.66	5.52
UP	2.97	-0.65	1.47
WB	2.95	2.33	2.70
Mean	3.74	2.99	3.43

During the sub-period of 1983-84 to 1996-97, the state of Orissa exhibits a decline in productivity, with rest of the states showing productivity improvements. ‘Small’ TFP gains are observed in Andhra Pradesh, Assam and Rajasthan, “medium” TFP gains in Bihar, Gujarat, Karnataka, Maharashtra, Uttar Pradesh and West Bengal. The states of Haryana, Kerala, Punjab and Tamil Nadu show ‘large’ productivity improvements.

has then been done on the basis of pace of overall economic reforms which essentially fastened only in second half of 1990s. These time periods are in line with those suggested by Prof Suresh D. Tendulkar in Nayak, Goldar and Agarwal (2010).

¹¹ Average annual growth rates computed through geometric means.

Table 1B: Categorization of states as per TFP growth rates

	1983-84 to 1996-97	1997-98 to 2005-6	1983-84 to 2005-6
Negative	ORR	BIH, GUJ, KAR, MAHA, UP	ORR
Marginal (0-1%)	MP	MP	GUJ, MP
Small (1-2%)	AP, ASS, RAJ		AP, BIH, KAR, MAHA, RAJ, UP
Medium (2-5%)	BIH, GUJ, KAR, MAHA, UP, WB	AP, ORR, RAJ, TN, WB	ASS, WB
Large (>5%)	HAR, KER, PUN, TN	ASS, HAR, KER, PUN	HAR, KER, PUN, TN

During the second sub-period 1997-98 to 2005-6, a decline in productivity is observed in five states- Bihar, Gujarat, Karnataka, Maharashtra and Uttar Pradesh. The TFP is observed to improve marginally in Madhya Pradesh. Assam, Haryana, Kerala, and Punjab show large TFP improvements; while the remaining states- Andhra Pradesh, Orissa, Rajasthan, Tamil Nadu, West Bengal show medium TFP improvements.

In order to shed light on the sources of TFP growth- whether it comes from efficiency change or from technical change, a **decomposition analysis of TFP indices** is performed. The states are grouped as per their performance on efficiency change (whether it is increasing or decreasing over time or no change), rate of technical progress and which component contributes more to productivity change. The results are laid out in Table 2A, 2B and 2C.

The overall Period (1983-84 to 2005-6): Efficiency is reported to decline in eight out of fifteen states- Andhra Pradesh, Bihar, Gujarat, Karnataka, Madhya Pradesh, Orissa, Uttar Pradesh and Maharashtra. The states of Assam, Haryana and Kerala report no change in efficiency- these being frontier states¹². Rajasthan, Tamil Nadu, West Bengal and Punjab report increases in efficiency¹³.

The Sequential Malmquist approach, by definition, rules out technical regress and hence all the states report technical progress. Large technical change occurs in three

¹² It is to be noted here that these states are always on the 'frontier', that is they are already operating at maximum efficiency levels. The states that are 'on' the frontier in several time-periods are Punjab and Tamil Nadu. The remaining states are never lying 'on' the frontier.

¹³ That the efficiency has improved has to be read with caution, since the efficiency levels in many states- before as well as after the improvement- are very low. There exists huge efficiency gaps, that is states can increase their production multi-fold simply by better utilizing resources. For example, in Madhya Pradesh, the efficiency gap is more than 70%, that is, the state is operating far below the attainable level of output.

states- Punjab, Haryana and Kerala- with the growth rate of technical change more than 5% for the entire time period.

As far as sources of productivity change are concerned, the technical change component assumes greater significance for all the states. Although efficiency is observed to decline in eight states, TFP regress occurs only in Orissa. This is due to positive counteracting effect of technical progress in the seven states while in Orissa the declining efficiency coupled with marginal technical progress pulls down overall productivity levels.

Table 2A: Technical Efficiency Change (TEC) and Technical Change (TC) (% per annum)

	1983-84 to 1996-97		1997-98 to 2005-6		1983-84 to 2005-6	
	TEC	TC	TEC	TC	TEC	TC
AP	-1.33	2.68	1.68	0.54	-0.11	1.80
ASS	0.00	1.84	0.00	8.58	0.00	4.54
BIH	-2.68	5.93	-0.91	0.08	-1.96	3.50
GUJ	0.23	2.68	-3.51	0.61	-1.32	1.83
HAR	0.00	8.36	0.00	8.34	0.00	8.35
KAR	0.13	2.88	-0.60	0.19	-0.17	1.77
KER	0.00	12.56	0.00	8.12	0.00	10.72
MAHA	1.80	1.87	-2.79	0.38	-0.10	1.26
MP	-0.40	0.88	0.57	0.34	-0.01	0.66
ORR	-2.94	0.61	2.15	0.01	-0.89	0.37
PUN	0.02	8.01	0.00	14.66	0.01	10.68
RAJ	0.10	1.25	0.89	1.81	0.42	1.48
TN	2.20	4.52	2.32	1.32	2.25	3.20
UP	-0.82	3.82	-1.25	0.60	-1.00	2.49
WB	0.49	2.43	2.33	0.00	1.24	1.43
mean	-0.22	3.97	0.04	2.95	-0.11	3.55

Table 2B: Categorization of states as per Technical Efficiency Change growth rates

	1983-84 to 1996-97	1997-98 to 2005-6	1983-84 to 2005-6
Declining	AP, BIH, MP, ORR, UP	BIH, GUJ, KAR, MAHA, UP	AP, BIH, GUJ, KAR, MP, MAHA, ORR, UP
No Change	ASS, HAR, KER	ASS, HAR, KER, PUN	ASS, HAR, KER
Increasing	GUJ, KAR, MAHA, PUN, RAJ, TN, WB	AP, MP, ORR, RAJ, TN, WB	PUN, RAJ, TN, WB

Table 2C: Categorization of states as per Technical Change growth rates (percent per annum)

	1983-84 to 1996-97	1997-98 to 2005-6	1984-85 to 2005-6
No change		WB	
Marginal (0-1)	MP, ORR	AP, BIH, GUJ, KAR, MP, MAHA, ORR, UP	MP, ORR
Small (1-2)	ASS, MAHA, RAJ,	RAJ, TN	AP, GUJ, KAR, MAHA, RAJ, WB
Medium (2-5)	AP, GUJ, KAR, TN, UP, WB		ASS, BIH, TN UP
Large (>5)	BIH, HAR, KER, PUN	ASS, HAR, KER, PUN	HAR, KER, PUN

The Sub-period 1983-84 to 1996-97: Efficiency is observed to decline in five out of fifteen states and is found to be improving in seven states (with Assam, Haryana and Kerala reporting no change in efficiency, being the frontier states).

Madhya Pradesh and Orissa report 'marginal' technical progress; and large technical progress is exhibited by Bihar, Haryana, Punjab and Kerala. The remaining states experience small and medium technical progress.

The contribution of technical change is greater than that of efficiency change to overall productivity changes in all states. Although efficiency decline is observed in five states, only Orissa reports overall productivity regress (that is attributable to low technical progress together with declining efficiency). In the remaining states, technical progress far outweighs the impact of declining efficiency and hence they report an overall productivity improvement.

The sub-period of 1997-1998 to 2005-6: Five states report a decline in efficiency- Bihar, Gujarat, Karnataka, Maharashtra, and Uttar Pradesh. All these states also report TFP regress since technical progress made did not outweigh the rate of efficiency decline. The non-frontier states of Andhra Pradesh, Madhya Pradesh, Orissa, Rajasthan, Tamil Nadu and West Bengal show improvements in efficiency.

The state of West Bengal exhibits technical stagnation while Assam, Haryana, Kerala and Punjab exhibit large technical progress.

The contribution of technical change is greater than that of efficiency change in ten out of fifteen states. The average technical progress seems to slow down further from nearly 4% in the previous period to 3% in this period.

Taking the average performance of all the fifteen states on the technical efficiency front, efficiency decline is observed in the first sub-period as well as overall time period, while being almost stagnant in second sub-period (Table 2A). Table 3 reports the states categorized as per their *technical efficiency scores*. The efficiency of five states- Madhya Pradesh, Uttar Pradesh, Andhra Pradesh, Karnataka, Maharashtra - is less than fifty percent implying even with existing technology, better utilization of resources would result in huge increases in output. The efficiency performance of Bihar has shown a declining trend over time- from around 70% during 1983-84 to 1996-97 to less than 50% during 1997-98 to 2005-6. The efficiency scores of Gujarat and West Bengal lie in the range 50-80% for all the time periods. The state of Rajasthan exhibits an improvement in efficiency score from 50-80% in the first sub-period to more than 80% in the second sub-period. Punjab and Assam operate beyond 80% of efficiency level, attaining full technical efficiency in several sub-periods. The state of Orissa also reports more-than-80% technical efficiency. Haryana remains technically efficient in all the sub-periods; while Kerala's efficiency falls little below 100% during 1997-98 to 2005-6 (otherwise remaining fully efficient in first sub period).

Table 3: Categorization of states as per Technical Efficiency Scores (percent)

		Less than fully Technically efficient			Fully technically efficient
		0-30	30-50	50-80	80-100
1983-84 to 1996-97	MP	AP, KAR, MAHA, UP	BIH, GUJ, RAJ, WB	ORR, PUN, TN, ASS	HAR, KER
1997-98 to 2005-6	UP	AP, BIH, KAR, MP, MAHA	GUJ, WB	ASS, KER, ORR, PUN, RAJ, TN	HAR
1983-84 to 2005-6	MP, UP	AP, KAR, MAHA	BIH, GUJ, RAJ, WB	ASS, KER, ORR, PUN, TN	HAR

V.2 TFP Results (excluding Bihar and Kerala)

When Malmquist TFP index is computed for thirteen states excluding Bihar and Kerala, the TFP growth, efficiency change and technical change are all computed with reference to a new frontier constructed for these states which would alter since one of the frontier states- Kerala- has been dropped. Hence results are liable to change. A comparison of the productivity results for thirteen states (excluding Bihar and Kerala) and fifteen states (including Bihar and Kerala) is presented in Table 4. The columns under 'A' are TFP growth rates excluding Bihar and Kerala and those under 'B' are computed including Bihar and Kerala (the latter discussed in previous sub-section). When correlation is computed across the two series of TFP growth rates for all the states, it is found that the two are highly correlated (correlation coefficient

being more than 0.95) with the exception of states of Karnataka and West Bengal (with correlation coefficient being 0.81 and 0.87 respectively). In most of the states, the direction of TFP change is the same although there is a change in the magnitude. A change in direction of productivity change is noted for Gujarat- in sub period 1 and overall time period when TFP improvement (computations including Bihar and Kerala- column B) gets replaced by productivity regress (computations excluding Bihar and Kerala- column A); and Karnataka in second sub-period when TFP regress (column B) is replaced by productivity improvement (column A).

Table 4: A comparison of TFP growth rates including and excluding Bihar and Kerala

	1983-84 to 1996-97		1997-98 to 2005-6		1983-84 to 2005-6		Correlation
	A	B	A	B	A	B	
AP	1.36	1.33	3.40	2.23	2.19	1.69	0.98
ASS	1.43	1.84	8.97	8.58	4.45	4.54	1.00
BIH		3.08		-0.84		1.46	
GUJ	-0.30	2.93	-2.62	-2.93	-1.25	0.49	0.95
HAR	9.18	8.36	10.21	8.34	9.60	8.35	0.96
KAR	2.56	2.99	3.21	-0.40	2.83	1.59	0.81
KER		12.56		8.11		10.72	
MAHA	3.47	3.71	-1.43	-2.44	1.44	1.15	0.97
MP	0.42	0.45	0.91	0.90	0.62	0.63	1.00
ORR	-2.33	-2.33	2.21	2.15	-0.50	-0.52	1.00
PUN	8.94	8.00	17.65	14.64	12.43	10.67	0.96
RAJ	1.50	1.37	2.71	2.71	2.00	1.92	1.00
TN	7.11	6.82	6.30	3.66	6.78	5.52	0.98
UP	2.97	2.97	-0.65	-0.65	1.48	1.47	1.00
WB	1.24	2.95	2.83	2.33	1.89	2.70	0.87
Mean	2.84	3.74	4.01	2.99	3.32	3.43	0.91

Section VI: Contemporaneous and Sequential Malmquist TFP Index- A Comparison of Results

The changes in TFP and its decomposition as obtained for fifteen states from the two alternate ways of frontier construction- contemporaneous and sequential- are hereby examined. As mentioned in Section III, Malmquist TFP index, when estimated using the notion of contemporaneous technology, gives rise to two biases- over-estimation of efficiency change and under-estimation of technical change. Table 5 lays down the growth rates of TFP, technical efficiency and technical change computed using the two notions for the overall time period 1983-84 to 2005-6. The mean TFP growth is found to be 1.6% and 3.4% per annum under contemporaneous and sequential technology respectively. In comparison to sequential approach, the technical efficiency change computed under contemporaneous approach is observed to be over-reported for all states (except Tamil Nadu) as well as on the average- mean technical efficiency growth rate being 0.41% p.a. under contemporaneous technology while it is estimated as -0.11% p.a. under sequential technology.

Table 5: TFP growth, Technical Efficiency Change and Technical Change (1983-84 to 2005-6) (percent per annum)

State	Contemporaneous Technology			Sequential Technology		
	TEC	TC	TFP	TEC	TC	TFP
AP	0.56	0.58	1.15	-0.11	1.80	1.69
ASS	0.00	-0.87	-0.87	0.00	4.54	4.54
BIH	-0.93	2.15	1.20	-1.96	3.50	1.46
GUJ	-0.70	0.50	-0.20	-1.32	1.83	0.49
HAR	0.00	3.71	3.71	0.00	8.35	8.35
KAR	0.68	1.13	1.82	-0.17	1.77	1.59
KER	0.00	3.97	3.97	0.00	10.72	10.72
MAHA	0.96	-1.26	-0.30	-0.10	1.26	1.15
MP	0.50	0.72	1.21	-0.01	0.66	0.63
ORR	0.00	-2.55	-2.55	-0.89	0.37	-0.52
PUN	0.00	8.47	8.47	0.01	10.68	10.67
RAJ	0.98	0.59	1.58	0.42	1.48	1.92
TN	2.25	0.23	2.49	2.25	3.20	5.52
UP	0.07	1.23	1.30	-1.00	2.49	1.47
WB	1.63	0.46	2.10	1.24	1.43	2.70
Mean	0.41	1.23	1.64	-0.11	3.55	3.43

When the entire time-period is considered, technical regress is reported in two frontier states- Assam and Orissa (Table 5). However it is useful to look at technical regress in frontier countries on year-to-year basis (see Table 6).

Table 6: Technical Regress in the states lying on the frontier in computation of contemporaneous Malmquist TFP index

Frontier States	Number of years for which technical regress is reported
<i>Always on the frontier</i>	
Assam	13
Haryana	9
Kerala	7
<i>For most of the years</i>	
Tamil Nadu	10
<i>For few years</i>	
Punjab	5
Rajasthan	3

The fact that there might be a fall in the use of one or more inputs causes technical regress under contemporaneous frontier. For states like Punjab, Haryana and Tamil Nadu- well known for adoption of new technology- a rise in use of fertilizers, tractors and irrigation is accompanied by a decline in inputs like livestock over the years.

Assam, apart from reduced use of livestock over the years, also witnessed a decline in the irrigation input since 2000 onwards due to large-scale devastation caused by floods. Kerala, another frontier state, reports a decline in the use of one of the inputs- livestock after 1996. The factors that have attributed to this decline are “scarcity of cheap and quality fodder, rapid increase in the price of feed and feed ingredients, inflow of cheap and low quality livestock products from neighbouring states, indiscriminate slaughter of animals, under exploitation of production potential of animals, non availability of good germplasm and threat from contagious diseases like FMD etc”¹⁴. The state of Rajasthan has witnessed a decline in gross cropped area and livestock in few years. Such declines in usage of inputs result in frontier receding inward causing biased TFP estimates. Hence there arises the need for constructing frontier using sequential technology.

Summing up

It is a matter of serious concern that efficiency decline is observed in almost fifty percent of the states. This implies huge potential increase in production even with existing technology. Some of these states do not report overall productivity regress only due to the fact that technical progress outweighs the impact of decline in efficiency. The technical stagnation and near-stagnation is observed in most of the states.

Demand for food would continue to rise and food supply has to keep pace in order to avoid shortages. This requires production to increase manifold. Since net area under cultivation has almost exhausted, productivity levels have to increase by leaps and bounds. It is necessary to reverse the efficiency decline that is exhibited by many states and achieve a faster and larger scale of diffusion of technical innovations across states.

¹⁴ <http://www.livestockkerala.org/livescen.htm>

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Appendix 1: Data envelopment Approach to computing Sequential Malmquist TFP Index

The output oriented constant returns to scale DEA model for M outputs and K inputs can be written as:

$$\begin{aligned} & \max_{\phi, \lambda} \phi, \\ \text{s.t.} \quad & -\phi y_i + Y\lambda \geq 0, \\ & x_i - X\lambda \geq 0, \\ & \lambda \geq 0, (1) \end{aligned}$$

where

y_i is a $M \times 1$ vector of output quantities for the i -th state;
 x_i is a $K \times 1$ vector of input quantities for the i -th state;
 Y is a $M \times N$ matrix of output quantities for all N states;
 X is a $K \times N$ matrix of input quantities for all N states;
 λ is a $N \times 1$ vector of weights; and ϕ is a scalar.

If there is only one output (as in the present case), the DEA model can be re-written as:

$$\begin{aligned} & \max_{\phi, \lambda} \phi, \\ \text{s.t.} \quad & -\phi y_i + Y\lambda \geq 0, \\ & x_i - X\lambda \geq 0, \\ & \lambda \geq 0, (1) \end{aligned}$$

where

y is the output quantity for the i -th state;
 x_i is a $K \times 1$ vector of input quantities for the i -th state;
 Y is a $1 \times N$ matrix of output quantities for all N states;
 X is a $K \times N$ matrix of input quantities for all N states;
 λ is a $N \times 1$ vector of weights; and ϕ is a scalar.

Four distance functions need to be calculated to measure the TFP change between two time periods that requires solving of following four linear programming problems.

$$\begin{aligned} [d_o^t(x_t, y_t)]^{-1} &= \max_{\phi, \lambda} \phi, \\ \text{st} \quad & -\phi y_{it} + \sum_{r=1 \text{ to } t} \sum_{n=1 \text{ to } N} \lambda_n^r y_n^r \geq 0 \\ & x_{it} - \sum_{r=1 \text{ to } t} \sum_{n=1 \text{ to } N} \lambda_k^r x_n^r \geq 0, \\ & \lambda_k^r \geq 0. \end{aligned}$$

$$\begin{aligned}
& [d_o^s(x_s, y_s)]^{-1} = \max_{\phi, \lambda} \phi, \\
\text{st} \quad & -\phi y_{is} + \sum_{r=1 \text{ to } s} \sum_{n=1 \text{ to } N} \lambda_n^r y_n^r \geq 0 \\
& x_{is} - \sum_{r=1 \text{ to } s} \sum_{n=1 \text{ to } N} \lambda_k^r x_n^r \geq 0, \\
& \lambda_k^r \geq 0.
\end{aligned}$$

$$\begin{aligned}
& [d_o^t(x_s, y_s)]^{-1} = \max_{\phi, \lambda} \phi, \\
\text{st} \quad & -\phi y_{is} + \sum_{r=1 \text{ to } t} \sum_{n=1 \text{ to } N} \lambda_n^r y_n^r \geq 0 \\
& x_{is} - \sum_{r=1 \text{ to } t} \sum_{n=1 \text{ to } N} \lambda_k^r x_n^r \geq 0, \\
& \lambda_k^r \geq 0.
\end{aligned}$$

$$\begin{aligned}
& [d_o^s(x_t, y_t)]^{-1} = \max_{\phi, \lambda} \phi, \\
\text{st} \quad & -\phi y_{it} + \sum_{r=1 \text{ to } s} \sum_{n=1 \text{ to } N} \lambda_n^r y_n^r \geq 0 \\
& x_{it} - \sum_{r=1 \text{ to } s} \sum_{n=1 \text{ to } N} \lambda_k^r x_n^r \geq 0, \\
& \lambda_k^r \geq 0.
\end{aligned}$$

Appendix 2

Table A1(a): Malmquist TFP Indices computed using sequential technology (including Bihar and Kerala)

	AP	ASS	BIH	GUJ	HAR	KAR	KER	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB
1985	1.09	1.125	1.271	1.17	1.129	1.108	1.203	1.151	1.029	0.828	1.076	0.915	1.638	1.214	1.263
1986	0.941	1.089	1.131	0.762	1.087	1.033	1.068	0.902	0.942	1.171	0.987	0.976	1.084	0.852	1.153
1987	0.928	0.951	1.223	1.171	1.133	1.012	1.059	0.903	1.014	0.919	1.061	1.237	1.071	1.435	1.008
1988	1.062	1.055	0.668	0.751	1.323	0.894	1.062	1.219	1.041	0.936	1.562	0.602	0.989	1.178	0.94
1989	1.171	0.949	1.416	1.512	1.091	0.95	1.096	0.921	0.998	1.22	0.805	1.855	1.059	0.799	1.095
1990	0.949	1.049	0.839	1.034	1.132	1.16	1.004	1.234	0.99	1.058	1.344	0.768	1.041	1.037	0.872
1991	1.111	0.966	1.16	0.863	1.043	0.96	1.155	0.944	0.855	0.777	0.937	1.541	1.05	1.015	1.047
1992	0.993	0.993	0.945	0.93	1.051	1.13	1.047	0.931	1.115	1.191	1.265	0.645	1.039	1.175	0.903
1993	1.059	1.014	0.944	1.322	1.029	1.144	1.164	1.213	1.049	0.89	0.976	1.234	1.146	0.891	1.136
1994	0.957	0.994	1.08	0.801	1.029	0.973	1.185	0.909	1.077	1.001	0.967	0.674	0.946	1.015	0.887
1995	0.956	1.02	0.999	1.147	1.04	0.905	1.219	1.05	0.835	0.885	1.053	1.402	1.183	0.975	1.145
1996	1.057	1.003	0.761	1.113	1.007	1.088	1.225	1.199	1.131	1.153	0.982	0.845	0.994	0.961	0.842
1997	0.935	1.047	1.252	1.094	1.028	1.081	1.175	1.013	1.031	0.813	1.235	1.286	0.818	0.999	1.206
1998	0.974	1.001	0.693	0.853	1.018	0.883	1.041	0.713	0.906	1.218	0.939	1.035	1.175	0.956	0.947
1999	1.23	0.958	1.182	1.045	1.022	1.057	1.086	1.205	1.174	0.96	1.003	1.076	1.089	1	0.959
2000	1.006	1.048	0.868	0.844	1.202	1.118	1.121	1.151	1.049	0.895	1.226	0.871	1.058	0.925	1.014
2001	1.134	1.594	1.223	0.815	1.011	1.154	0.918	0.831	1.177	1.018	1.088	0.816	0.809	1.002	1.079
2002	0.919	1.035	0.885	1.45	1.083	0.872	1.068	1.148	0.929	1.17	1.073	1.646	1.01	1.032	1.129
2003	0.879	1.021	1.337	0.692	1.088	0.91	1.098	1.043	1.186	1.111	0.996	0.575	0.809	1.16	0.911
2004	0.963	1.007	0.754	1.685	1.154	0.75	1.128	0.928	0.79	0.786	1.415	1.916	0.881	0.78	1.082
2005	1.185	1.155	1.281	0.879	1.15	1.506	1.142	1.026	1.032	1.209	1.412	0.946	1.395	1.271	0.982
2006	0.968	1.065	0.933	0.84	1.04	0.894	1.148	0.855	0.919	0.92	1.275	0.937	1.257	0.897	1.133

Table A1(b): Technical Change Component of Malmquist TFP indices computed using sequential technology (including Bihar and Kerala)

	AP	ASS	BIH	GUJ	HAR	KAR	KER	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB	mean
1985	1.022	1.125	1.144	1.037	1.129	1.075	1.203	1.041	1.01	1.001	1.1	1.033	1.003	1.003	1.083	1.066
1986	1.083	1.089	1.136	1.054	1.087	1.145	1.068	1.134	1.059	1.023	1.027	1.004	1.084	1.061	1.148	1.079
1987	1.018	1	1.092	1.051	1.133	1.017	1.059	1.003	1	1	1.079	1.036	1.071	1.113	1.051	1.047
1988	1.003	1.003	1.004	1.032	1.323	1.006	1.062	1	1	1	1.444	1.064	1.001	1.186	1	1.068
1989	1.02	1	1	1.006	1.091	1.012	1.096	1.002	1.001	1.001	1.069	1	1.046	1.002	1	1.023
1990	1.029	1	1.003	1.03	1.132	1.003	1.004	1.005	1.002	1.051	1.1	1.027	1.041	1.001	1	1.028
1991	1.012	1	1.159	1.016	1.043	1.04	1.155	1.004	1.004	1	1.043	1.001	1.05	1.028	1.025	1.038
1992	1.041	1.001	1.01	1.015	1.051	1.002	1.047	1.002	1.001	1	1.046	1	1.039	1	1.003	1.017
1993	1.069	1.002	1.022	1.053	1.029	1.004	1.164	1.019	1.019	1.002	1.02	1	1.146	1.108	1.008	1.043
1994	1	1	1	1	1.029	1	1.185	1	1	1	1.006	1	1	1	1	1.014
1995	1.053	1	1.039	1.045	1.04	1.004	1.219	1.021	1.018	1.002	1	1	1.119	1.015	1.004	1.037
1996	1	1	1.191	1.01	1.007	1.076	1.225	1	1.001	1	1.086	1	1	1	1	1.037
1997	1.002	1.028	1	1.002	1.028	1.001	1.175	1.02	1.001	1.001	1.082	1	1	1	1.005	1.022
1998	1	1.001	1	1	1.018	1	1.041	1	1	1	1	1	1	1	1	1.004
1999	1.012	1.001	1	1.014	1.022	1.002	1.086	1.004	1.008	1	1.003	1	1.041	1	1	1.013
2000	1.034	1.003	1	1.032	1.202	1.01	1.121	1.007	1.012	1.001	1.227	1	1.058	1.042	1	1.048
2001	1	1.594	1	1	1.011	1	1	1	1	1	1.022	1	1	1	1	1.034
2002	1.001	1.035	1	1.001	1.083	1.003	1	1.018	1	1	1.073	1.066	1	1.001	1	1.018
2003	1	1.021	1	1	1.088	1	1.077	1	1	1	1.096	1	1	1.012	1	1.019
2004	1	1.007	1	1	1.154	1	1.128	1	1.007	1	1.286	1.102	1.001	1	1	1.043
2005	1	1.155	1	1.006	1.15	1.002	1.142	1.002	1.004	1	1.412	1	1.003	1	1	1.053
2006	1.002	1.065	1.007	1.002	1.04	1	1.148	1.003	1	1	1.275	1	1.018	1	1	1.035

Table A1(c): Technical Efficiency Change Component of Malmquist TFP indices computed using sequential technology (including Bihar and Kerala)

	AP	ASS	BIH	GUJ	HAR	KAR	KER	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB	mean
1985	1.066	1	1.111	1.128	1	1.031	1	1.106	1.018	0.827	0.978	0.886	1.633	1.21	1.167	1.065
1986	0.869	1	0.995	0.723	1	0.902	1	0.795	0.89	1.144	0.961	0.972	1	0.804	1.004	0.931
1987	0.912	0.951	1.12	1.114	1	0.995	1	0.9	1.014	0.919	0.984	1.193	1	1.289	0.959	1.018
1988	1.059	1.052	0.666	0.728	1	0.889	1	1.219	1.041	0.936	1.082	0.565	0.988	0.994	0.939	0.927
1989	1.148	0.949	1.416	1.503	1	0.939	1	0.92	0.997	1.219	0.754	1.855	1.012	0.797	1.095	1.076
1990	0.922	1.049	0.836	1.003	1	1.157	1	1.227	0.988	1.007	1.221	0.748	1	1.035	0.871	0.996
1991	1.098	0.966	1.001	0.849	1	0.924	1	0.94	0.852	0.777	0.898	1.539	1	0.988	1.022	0.979
1992	0.953	0.992	0.936	0.916	1	1.127	1	0.929	1.114	1.19	1.209	0.645	1	1.175	0.901	0.995
1993	0.991	1.012	0.924	1.256	1	1.14	1	1.191	1.03	0.888	0.957	1.234	1	0.804	1.127	1.029
1994	0.957	0.994	1.08	0.801	1	0.973	1	0.909	1.077	1.001	0.962	0.674	0.946	1.015	0.887	0.946
1995	0.907	1.02	0.962	1.098	1	0.902	1	1.029	0.821	0.883	1.053	1.402	1.057	0.961	1.139	1.008
1996	1.057	1.003	0.639	1.102	1	1.011	1	1.199	1.13	1.153	0.905	0.845	0.994	0.961	0.842	0.979
1997	0.933	1.018	1.252	1.092	1	1.08	1	0.993	1.031	0.812	1.142	1.286	0.818	0.999	1.2	1.035
1998	0.974	1	0.693	0.853	1	0.883	1	0.713	0.906	1.218	0.939	1.035	1.175	0.956	0.947	0.943
1999	1.215	0.957	1.182	1.031	1	1.055	1	1.201	1.166	0.96	1	1.076	1.047	1	0.959	1.053
2000	0.973	1.045	0.868	0.818	1	1.107	1	1.143	1.036	0.895	1	0.871	1	0.887	1.014	0.973
2001	1.134	1	1.223	0.815	1	1.154	0.918	0.831	1.177	1.018	1.065	0.816	0.809	1.002	1.079	0.993
2002	0.918	1	0.885	1.448	1	0.869	1.068	1.127	0.929	1.17	1	1.544	1.01	1.031	1.129	1.061
2003	0.879	1	1.337	0.692	1	0.91	1.02	1.043	1.186	1.111	0.909	0.575	0.809	1.146	0.911	0.949
2004	0.963	1	0.754	1.685	1	0.75	1	0.928	0.785	0.786	1.1	1.738	0.88	0.78	1.082	0.981
2005	1.185	1	1.281	0.874	1	1.503	1	1.025	1.028	1.209	1	0.946	1.391	1.271	0.982	1.100
2006	0.966	1	0.927	0.838	1	0.893	1	0.852	0.919	0.92	1	0.937	1.235	0.897	1.133	0.963

Table A2(a): Malmquist TFP Indices computed using sequential technology (excluding Bihar and Kerala)

	AP	ASS	GUJ	HAR	KAR	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB	mean
1985	1.09	1.125	0.76	1.128	0.999	1.117	1.029	0.827	1.076	0.916	1.638	1.213	1.675	1.096
1986	0.941	1.089	0.762	1.105	1.003	0.903	0.942	1.171	0.997	0.976	1.084	0.853	1.131	0.990
1987	0.934	0.951	1.211	1.16	1.014	0.905	1.009	0.92	1.051	1.267	1.076	1.434	1.015	1.063
1988	1.062	1.005	0.751	1.322	0.946	1.218	1.041	0.936	1.536	0.601	0.989	1.179	0.914	1.012
1989	1.171	0.948	1.511	1.123	0.998	0.967	0.998	1.22	0.859	1.855	1.059	0.799	1.041	1.091
1990	0.949	1.05	1.034	1.132	1.103	1.176	0.99	1.058	1.317	0.768	1.041	1.037	0.707	1.016
1991	1.106	0.965	0.863	1.067	0.86	0.973	0.855	0.777	0.973	1.541	1.051	1.015	0.867	0.979
1992	0.993	0.993	0.929	1.05	1.159	0.899	1.115	1.191	1.223	0.645	1.044	1.175	0.896	1.011
1993	1.058	1.014	1.322	1.029	1.139	1.214	1.049	0.89	1.004	1.234	1.146	0.891	1.136	1.080
1994	0.956	0.993	0.801	1.028	1.035	0.91	1.077	1.001	1.042	0.674	0.973	1.015	0.887	0.946
1995	0.957	1.019	1.168	1.042	0.975	1.05	0.836	0.885	1.081	1.402	1.167	0.975	1.145	1.045
1996	1.056	1.009	1.077	1.008	1.008	1.199	1.13	1.153	1.008	0.84	0.994	0.961	0.842	1.017
1997	0.939	1.04	1.095	1.035	1.137	1.013	1.032	0.813	1.146	1.286	0.826	0.999	1.203	1.035
1998	0.97	1.004	0.876	1.018	0.932	0.714	0.906	1.218	0.96	1.035	1.179	0.956	0.947	0.970
1999	1.248	0.969	1.053	1.041	1.235	1.291	1.175	0.96	1.061	1.076	1.132	1	0.959	1.087
2000	1.006	1.053	0.838	1.203	1.026	1.092	1.049	0.896	1.175	0.871	1.058	0.925	1.017	1.011
2001	1.144	1.604	0.815	1.048	1.126	0.832	1.177	1.018	1.085	0.816	0.838	1.002	1.077	1.027
2002	0.915	1.035	1.45	1.084	0.862	1.147	0.928	1.171	1.062	1.646	1.075	1.032	1.129	1.101
2003	0.875	1.029	0.693	1.088	0.839	1.043	1.187	1.11	1.009	0.575	0.774	1.16	0.911	0.927
2004	0.963	1.007	1.685	1.252	0.88	0.927	0.79	0.786	1.567	1.916	0.999	0.78	1.085	1.077
2005	1.185	1.153	0.879	1.145	1.405	1.027	1.032	1.212	1.46	0.946	1.485	1.271	0.992	1.154
2006	1.061	1.066	0.84	1.062	1.118	0.921	0.919	0.922	1.357	0.937	1.186	0.897	1.167	1.026
Mean	1.022	1.044	0.987	1.096	1.028	1.014	1.006	0.995	1.124	1.020	1.068	1.015	1.019	1.033

Table A2(b): Technical Change Component of Malmquist TFP indices computed using sequential technology (excluding Bihar and Kerala)

	AP	ASS	GUJ	HAR	KAR	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB	mean
1985	1.022	1.125	1.119	1.128	1.04	1.036	1.01	1.001	1.1	1.033	1.003	1.003	1.038	1.050
1986	1.083	1.089	1.055	1.105	1.107	1.135	1.059	1.023	1.037	1.004	1.084	1.061	1.102	1.072
1987	1.059	1	1.086	1.16	1.32	1.055	1.005	1	1.216	1.062	1.076	1.113	2.064	1.147
1988	1.003	1.003	1.031	1.322	1	1	1	1	1.427	1.064	1.001	1.185	1	1.072
1989	1.02	1	1.006	1.123	1.009	1.004	1.001	1.001	1.109	1	1.046	1.002	1.002	1.024
1990	1.029	1	1.03	1.132	1	1.003	1.002	1.051	1.074	1.027	1.041	1.001	1	1.029
1991	1.008	1	1.016	1.067	1	1.002	1.004	1	1.098	1.001	1.051	1.028	1	1.021
1992	1.041	1	1.015	1.05	1	1.001	1.001	1	1.031	1	1.044	1	1.002	1.014
1993	1.069	1	1.053	1.029	1	1.019	1.019	1.002	1.025	1	1.146	1.108	1	1.035
1994	1	1	1	1.028	1.001	1	1	1	1.021	1	1	1	1	1.004
1995	1.053	1	1.038	1.042	1.008	1.021	1.018	1.002	1.081	1	1.135	1.015	1.004	1.031
1996	1	1	1	1.008	1	1	1	1	1.008	1	1	1	1	1.001
1997	1.003	1.028	1.003	1.035	1.01	1.019	1.001	1.001	1.146	1	1.001	1	1.003	1.019
1998	1	1.004	1	1.018	1	1	1	1	1	1	1	1	1	1.002
1999	1.019	1	1.045	1.041	1.036	1.001	1.008	1	1.019	1	1.094	1	1	1.020
2000	1.041	1.02	1.032	1.203	1.039	1.015	1.012	1.001	1.175	1	1.058	1.042	1.001	1.047
2001	1	1.604	1	1.048	1.031	1.011	1	1	1.085	1	1	1	1	1.051
2002	1	1.035	1.001	1.084	1.011	1.018	1	1	1.062	1.066	1	1.001	1	1.021
2003	1	1.029	1	1.088	1.028	1	1	1	1.042	1	1	1.011	1	1.015
2004	1	1.007	1	1.252	1.009	1	1.007	1	1.518	1.102	1.007	1	1	1.061
2005	1	1.153	1.006	1.145	1.002	1.002	1.004	1	1.46	1	1.026	1	1	1.055
2006	1.007	1.066	1.001	1.062	1.025	1.003	1	1	1.357	1	1.186	1	1	1.050

Table A2(c): Technical Efficiency Change Component of Malmquist TFP indices computed using sequential technology (excluding Bihar and Kerala)

	AP	ASS	GUJ	HAR	KAR	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB	mean
1985	1.066	1	0.679	1	0.961	1.079	1.019	0.827	0.978	0.887	1.633	1.21	1.614	1.044
1986	0.87	1	0.722	1	0.906	0.796	0.889	1.144	0.962	0.971	1	0.804	1.026	0.923
1987	0.882	0.951	1.115	1	0.768	0.858	1.004	0.92	0.864	1.193	1	1.288	0.492	0.927
1988	1.059	1.052	0.728	1	0.946	1.218	1.041	0.936	1.077	0.565	0.988	0.994	0.914	0.948
1989	1.148	0.948	1.502	1	0.989	0.963	0.997	1.219	0.775	1.855	1.012	0.797	1.039	1.065
1990	0.922	1.05	1.004	1	1.103	1.172	0.988	1.007	1.227	0.748	1	1.035	0.707	0.987
1991	1.098	0.965	0.85	1	0.86	0.972	0.852	0.777	0.886	1.539	1	0.987	0.867	0.959
1992	0.954	0.993	0.916	1	1.159	0.899	1.114	1.191	1.187	0.645	1	1.175	0.894	0.997
1993	0.99	1.014	1.255	1	1.139	1.192	1.03	0.888	0.979	1.234	1	0.804	1.128	1.042
1994	0.956	0.993	0.801	1	1.034	0.91	1.077	1.001	1.021	0.674	0.973	1.015	0.887	0.943
1995	0.908	1.019	1.125	1	0.967	1.028	0.821	0.883	1	1.402	1.028	0.961	1.139	1.013
1996	1.056	1.009	1.077	1	1.008	1.199	1.13	1.153	1	0.845	0.994	0.961	0.842	1.016
1997	0.936	1.012	1.092	1	1.126	0.993	1.031	0.812	1	1.286	0.825	0.999	1.2	1.016
1998	0.97	1	0.876	1	0.932	0.714	0.906	1.218	0.96	1.035	1.179	0.956	0.947	0.969
1999	1.225	0.969	1.008	1	1.191	1.289	1.165	0.96	1.042	1.076	1.035	1	0.959	1.066
2000	0.966	1.032	0.813	1	0.988	1.077	1.036	0.895	1	0.871	1	0.887	1.017	0.965
2001	1.144	1	0.815	1	1.092	0.823	1.177	1.018	1	0.816	0.838	1.002	1.077	0.977
2002	0.915	1	1.448	1	0.853	1.126	0.928	1.171	1	1.544	1.075	1.031	1.129	1.079
2003	0.875	1	0.693	1	0.816	1.043	1.187	1.11	0.968	0.575	0.774	1.147	0.911	0.913
2004	0.963	1	1.685	1	0.872	0.927	0.785	0.74	1.033	1.739	0.992	0.78	1.085	1.011
2005	1.185	1	0.874	1	1.402	1.025	1.028	1.212	1	0.946	1.47	1.271	0.992	1.095
2006	1.054	1	0.839	1	1.091	0.919	0.919	0.922	1	0.937	1	0.897	1.167	0.977

Table A3(a): Malmquist TFP Indices computed using contemporaneous technology (including Bihar and Kerala)

	AP	ASS	BIH	GUJ	HAR	KAR	KER	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB	mean
1985	1.12	1.034	1.271	1.185	1.081	1.051	1.203	0.983	1.269	0.752	1.076	0.903	1.535	1.184	1.263	1.113
1986	0.913	1.039	1.131	0.811	1.048	1.033	1.054	0.853	0.976	1.157	0.977	0.97	1.097	0.866	1.153	1
1987	0.928	0.856	1.221	1.207	1.152	1.011	1.003	0.831	1.119	0.899	1.067	1.204	1.062	1.382	1.006	1.053
1988	1.07	0.958	0.667	0.717	1.23	0.929	0.972	1.463	0.859	1	1.522	0.613	0.898	1.164	0.944	0.97
1989	1.179	0.887	1.415	1.559	0.835	0.93	1.086	1.05	0.849	1.143	0.583	1.829	1.124	0.792	1.096	1.049
1990	0.97	1.095	0.841	1.002	1.34	1.187	0.94	1.194	1.051	1.074	1.472	0.792	1.002	1.06	0.898	1.047
1991	1.075	0.844	1.16	0.858	0.854	0.939	1.194	0.803	0.948	0.785	0.852	1.515	1.084	1.016	1.059	0.983
1992	0.985	1.011	0.94	0.931	1.175	1.17	0.944	0.872	1.183	1.166	1.323	0.649	0.979	1.23	0.872	1.014
1993	1.045	1.145	0.926	1.319	1.016	1.114	1.162	1.259	1.02	0.844	0.976	1.231	1.213	0.867	1.101	1.074
1994	0.966	0.781	1.08	0.792	0.911	0.957	1.155	0.893	1.102	0.938	0.927	0.673	0.758	1.024	0.894	0.914
1995	0.949	1.234	0.997	1.139	0.989	0.912	1.157	0.836	0.991	0.837	1.052	1.385	1.338	1.005	1.135	1.052
1996	1.056	0.909	0.762	1.127	0.978	1.069	1.23	1.298	1.152	1.291	0.98	0.824	0.886	0.973	0.798	1.009
1997	0.869	1.093	1.249	1.045	1.043	1.079	1.096	1.074	0.932	0.767	1.233	1.314	0.701	0.967	1.232	1.031
1998	1.027	0.899	0.682	0.822	0.951	0.885	0.911	0.641	0.882	1.072	0.929	1.069	1.243	0.966	0.947	0.917
1999	1.232	0.911	1.146	1.049	0.972	1.097	1.004	1.47	0.951	1.007	1.028	1.077	1.101	1.011	0.948	1.059
2000	1.025	0.89	0.841	0.874	1.336	1.096	1.057	0.969	1.237	0.836	1.222	0.897	1.043	0.912	1.029	1.007
2001	1.094	1.431	1.31	0.84	0.874	1.15	0.77	1.09	0.953	1.085	1.086	0.831	0.777	1.008	1.086	1.01
2002	0.911	0.959	0.864	1.295	1.036	0.865	0.934	0.88	1.133	1.057	1.07	1.636	0.937	1.047	1.061	1.031
2003	0.896	0.952	1.399	0.715	1.079	0.898	0.991	1.241	1.019	1.15	0.999	0.579	0.856	1.1	0.876	0.963
2004	0.919	0.994	0.696	1.549	1.017	0.775	1.012	0.74	0.927	0.781	1.347	1.798	0.84	0.769	1.124	0.98
2005	1.236	1.091	1.305	0.927	1.127	1.556	1.058	1.1	1.032	1.222	1.419	0.926	1.295	1.296	0.944	1.155
2006	0.904	0.998	0.953	0.782	0.958	0.936	1.073	0.902	0.838	0.865	1.217	0.911	1.211	0.887	1.156	0.964
Mean	1.011	0.991	1.012	0.998	1.037	1.018	1.04	0.997	1.012	0.975	1.085	1.016	1.025	1.013	1.021	1.016

Table A3(b): Technical Efficiency Change component of Malmquist TFP Indices computed using contemporaneous technology (including Bihar and Kerala)

	AP	ASS	BIH	GUJ	HAR	KAR	KER	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB	mean
1985	1.168	1	1.111	1.189	1	1.02	1	1.174	1.255	1	0.98	1.135	1.633	1.242	1.167	1.128
1986	0.793	1	0.995	0.72	1	0.902	1	0.722	0.825	1	1.004	0.863	1	0.81	1.005	0.903
1987	0.95	1	1.133	1.195	1	1.066	1	0.899	1.209	1	0.949	1.219	1	1.245	1.005	1.053
1988	1.11	1	0.738	0.738	1	0.944	1	1.608	0.949	1	1.072	0.594	1	1.093	1.034	0.969
1989	1.168	1	1.376	1.522	1	0.969	1	0.931	0.894	1	0.761	1.669	1	0.855	1.098	1.059
1990	0.938	1	0.881	0.953	1	1.175	1	1.154	1.011	1	1.214	0.753	1	0.924	0.913	0.988
1991	1.023	1	0.874	0.82	1	0.85	1	0.909	0.84	1	0.895	1.392	1	1.103	0.929	0.967
1992	0.952	1	1.109	0.905	1	1.232	1	0.794	1.257	1	1.209	0.724	1	1.146	0.934	1.006
1993	0.979	1	0.852	1.262	1	1.098	1	1.368	0.976	1	0.958	1.257	1	0.737	1.08	1.027
1994	1.111	1	1.057	0.879	1	1.059	1	0.922	1.325	1	0.984	0.717	1	1.446	1.105	1.028
1995	0.787	1	0.953	0.995	1	0.795	1	0.833	0.769	1	1.031	1.298	1	0.735	0.889	0.929
1996	1.133	1	0.641	1.153	1	0.999	1	1.193	1.296	1	0.972	0.868	1	0.983	0.862	0.995
1997	1.006	1	1.483	1.15	1	1.063	1	1.263	0.824	1	1.058	1.36	1	1.267	1.103	1.094
1998	0.906	1	0.672	0.793	1	0.941	1	0.609	0.912	1	1	1	1	0.9	1.002	0.906
1999	1.188	1	1.108	1.029	1	1.14	1	1.485	1.007	1	1	1	1	0.969	1.029	1.057
2000	0.977	1	0.819	0.855	1	0.982	1	1.072	1.204	1	0.946	1	1	0.742	0.993	0.967
2001	1.278	1	1.39	1.015	1	1.248	1	1.053	0.951	1	1.057	0.861	1	1.124	1.22	1.071
2002	0.951	1	0.849	1.309	1	0.85	1	0.824	1.087	1	1	1.161	1	1.084	0.992	1
2003	0.93	1	1.342	0.65	1	0.89	1	1.201	0.998	1	0.921	0.681	1	0.873	0.959	0.949
2004	1.053	1	0.792	1.66	1	0.81	1	0.79	1.026	1	1.086	1.469	0.964	0.919	1.12	1.025
2005	1.044	1	1.215	0.894	1	1.495	1	1.004	0.997	1	1	1	1.037	1.141	0.945	1.044
2006	0.852	1	0.989	0.806	1	0.89	1	1.023	0.795	1	1	1	1	1.056	1.061	0.961
Mean	1.006	1	0.991	0.993	1	1.007	1	1.01	1.005	1	1	1.01	1.023	1.001	1.016	1.004

Table A3(c): Technical Change component of Malmquist TFP Indices computed using contemporaneous technology (including Bihar and Kerala)

	AP	ASS	BIH	GUJ	HAR	KAR	KER	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB	mean
1985	0.959	1.034	1.144	0.997	1.081	1.03	1.203	0.837	1.011	0.752	1.099	0.796	0.94	0.954	1.082	0.987
1986	1.151	1.039	1.136	1.127	1.048	1.145	1.054	1.181	1.184	1.157	0.973	1.124	1.097	1.069	1.148	1.107
1987	0.976	0.856	1.078	1.01	1.152	0.948	1.003	0.924	0.925	0.899	1.125	0.988	1.062	1.11	1.001	1
1988	0.965	0.958	0.904	0.971	1.23	0.984	0.972	0.91	0.904	1	1.419	1.032	0.898	1.066	0.913	1
1989	1.009	0.887	1.028	1.024	0.835	0.96	1.086	1.128	0.95	1.143	0.765	1.095	1.124	0.927	0.999	0.991
1990	1.034	1.095	0.954	1.052	1.34	1.01	0.94	1.035	1.04	1.074	1.213	1.051	1.002	1.148	0.983	1.06
1991	1.051	0.844	1.327	1.047	0.854	1.105	1.194	0.883	1.129	0.785	0.952	1.089	1.084	0.921	1.139	1.017
1992	1.035	1.011	0.848	1.028	1.175	0.95	0.944	1.098	0.941	1.166	1.094	0.897	0.979	1.074	0.934	1.007
1993	1.068	1.145	1.087	1.045	1.016	1.015	1.162	0.92	1.045	0.844	1.019	0.979	1.213	1.177	1.02	1.046
1994	0.869	0.781	1.022	0.901	0.911	0.903	1.155	0.968	0.832	0.938	0.942	0.939	0.758	0.708	0.809	0.889
1995	1.205	1.234	1.047	1.145	0.989	1.147	1.157	1.003	1.289	0.837	1.02	1.067	1.338	1.368	1.276	1.132
1996	0.932	0.909	1.189	0.977	0.978	1.07	1.23	1.088	0.889	1.291	1.009	0.949	0.886	0.989	0.926	1.014
1997	0.864	1.093	0.842	0.908	1.043	1.015	1.096	0.85	1.131	0.767	1.166	0.966	0.701	0.763	1.117	0.943
1998	1.134	0.899	1.014	1.036	0.951	0.94	0.911	1.053	0.967	1.072	0.929	1.069	1.243	1.074	0.945	1.012
1999	1.037	0.911	1.034	1.02	0.972	0.962	1.004	0.99	0.945	1.007	1.028	1.077	1.101	1.043	0.921	1.002
2000	1.049	0.89	1.027	1.022	1.336	1.116	1.057	0.903	1.028	0.836	1.292	0.897	1.043	1.229	1.037	1.042
2001	0.856	1.431	0.943	0.828	0.874	0.922	0.77	1.036	1.003	1.085	1.027	0.965	0.777	0.896	0.891	0.942
2002	0.958	0.959	1.018	0.989	1.036	1.019	0.934	1.067	1.043	1.057	1.07	1.409	0.937	0.966	1.07	1.03
2003	0.963	0.952	1.043	1.1	1.079	1.009	0.991	1.034	1.021	1.15	1.085	0.851	0.856	1.26	0.913	1.015
2004	0.873	0.994	0.88	0.933	1.017	0.957	1.012	0.936	0.904	0.781	1.24	1.224	0.871	0.836	1.003	0.957
2005	1.183	1.091	1.073	1.037	1.127	1.041	1.058	1.096	1.034	1.222	1.419	0.926	1.249	1.136	0.999	1.107
2006	1.062	0.998	0.964	0.97	0.958	1.051	1.073	0.882	1.055	0.865	1.217	0.911	1.211	0.84	1.089	1.004
Mean	1.006	0.991	1.022	1.005	1.037	1.011	1.04	0.987	1.007	0.975	1.085	1.006	1.002	1.012	1.005	1.012

Table A4(a): Malmquist TFP Indices computed using contemporaneous technology (excluding Bihar and Kerala)

	AP	ASS	GUJ	HAR	KAR	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB	mean
1985	1.123	1.038	1.186	1.128	0.999	1.232	0.982	0.752	1.076	0.903	1.535	1.184	1.675	1.117
1986	0.913	1.039	0.811	1.061	1.003	0.976	0.853	1.154	0.983	0.969	1.097	0.879	1.131	0.985
1987	0.928	0.856	1.208	1.14	1.021	1.118	0.831	0.9	1.065	1.204	1.062	1.36	1.047	1.047
1988	1.072	0.902	0.718	1.199	0.944	0.859	1.462	1	1.469	0.613	0.899	1.165	0.924	0.988
1989	1.182	0.911	1.541	0.881	0.994	0.85	1.049	1.192	0.596	1.829	1.123	0.796	1.037	1.035
1990	0.972	1.062	1	1.318	1.107	1.051	1.194	1.025	1.454	0.792	1.008	1.048	0.727	1.042
1991	1.048	0.844	0.861	0.863	0.86	0.968	0.805	0.79	0.876	1.515	1.084	1.015	0.886	0.941
1992	0.99	1.01	0.934	1.159	1.159	1.034	0.871	1.156	1.288	0.649	0.99	1.235	0.816	1.007
1993	1.035	1.144	1.311	1.015	1.136	1.028	1.258	0.844	1.001	1.231	1.213	0.866	1.059	1.079
1994	0.965	0.787	0.794	0.911	1.031	1.12	0.9	0.938	0.992	0.675	0.782	1.023	0.919	0.903
1995	0.949	1.234	1.176	0.991	0.973	0.981	0.862	0.843	1.081	1.38	1.338	1.004	1.111	1.059
1996	1.052	0.912	1.055	0.971	1.003	1.131	1.259	1.292	1.001	0.827	0.878	0.973	0.844	1.006
1997	0.881	1.093	1.059	1.047	1.136	0.933	1.074	0.769	1.165	1.308	0.718	0.968	1.189	1.013
1998	1.027	0.912	0.829	0.937	0.931	0.882	0.651	1.073	0.936	1.069	1.243	0.966	0.958	0.945
1999	1.232	0.926	1.05	1.005	1.233	0.981	1.443	1.003	1.055	1.078	1.125	1.011	0.951	1.076
2000	1.025	0.907	0.88	1.337	1.025	1.236	0.957	0.844	1.187	0.897	1.043	0.913	1.028	1.012
2001	1.104	1.431	0.84	0.903	1.13	0.957	1.09	1.084	1.085	0.831	0.79	1.007	1.085	1.014
2002	0.912	0.959	1.294	1.036	0.868	1.129	0.881	1.057	1.062	1.635	0.96	1.047	1.048	1.053
2003	0.895	0.96	0.715	1.079	0.833	1.02	1.24	1.15	1.009	0.579	0.855	1.101	0.88	0.93
2004	0.919	0.997	1.549	1.086	0.874	0.927	0.741	0.784	1.464	1.798	0.84	0.769	1.129	1.026
2005	1.236	1.091	0.927	1.128	1.412	1.032	1.098	1.212	1.449	0.926	1.295	1.296	0.937	1.144
2006	0.914	0.998	0.782	0.965	1.114	0.917	0.904	0.867	1.294	0.911	1.195	0.887	1.167	0.983
Mean	1.012	0.992	0.997	1.046	1.028	1.011	0.997	0.975	1.096	1.016	1.03	1.013	1.01	1.017

Table A4(b): Technical Efficiency Change component of Malmquist TFP Indices computed using contemporaneous technology (excluding Bihar and Kerala)

Year	AP	ASS	GUJ	HAR	KAR	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB	mean
1985	1.168	1	1.189	1	0.961	1.226	1.174	1	0.978	1.136	1.633	1.242	1.614	1.161
1986	0.794	1	0.72	1	0.906	0.824	0.723	1	1.005	0.863	1	0.83	1.026	0.892
1987	0.951	1	1.196	1	1.098	1.209	0.899	1	0.961	1.219	1	1.215	1.061	1.057
1988	1.114	1	0.738	1	0.945	0.949	1.607	1	1.059	0.594	1	1.093	0.965	0.982
1989	1.185	1	1.525	1	1.008	0.895	0.931	1	0.776	1.669	1	0.863	1.036	1.044
1990	0.921	1	0.95	1	1.163	1.011	1.154	1	1.225	0.753	1	0.914	0.777	0.981
1991	1.027	1	0.822	1	0.915	0.972	0.916	1	0.886	1.392	1	1.094	0.924	0.988
1992	0.953	1	0.907	1	1.223	1.086	0.789	1	1.187	0.724	1	1.156	0.862	0.981
1993	0.979	1	1.258	1	1.097	0.988	1.372	1	0.979	1.257	1	0.734	1.036	1.042
1994	1.111	1	0.888	1	1.012	1.362	0.925	1	1.021	0.722	1	1.453	1.108	1.031
1995	0.794	1	1.037	1	0.911	0.763	0.854	1	1	1.288	1	0.723	0.886	0.933
1996	1.185	1	1.106	1	1.015	1.269	1.187	1	1	0.889	1	0.98	0.893	1.035
1997	0.947	1	1.136	1	1.081	0.815	1.234	1	1	1.329	1	1.292	1.064	1.06
1998	0.906	1	0.808	1	0.912	0.911	0.631	1	1	1	1	0.899	1.006	0.922
1999	1.188	1	1.007	1	1.136	1.009	1.484	1	1	1	1	0.969	1.032	1.056
2000	0.977	1	0.858	1	0.954	1.201	1.034	1	1	1	1	0.742	0.994	0.976
2001	1.285	1	1.015	1	1.145	0.949	1.053	1	1	0.862	1	1.124	1.224	1.045
2002	0.949	1	1.309	1	0.855	1.087	0.826	1	1	1.161	1	1.084	0.986	1.013
2003	0.928	1	0.65	1	0.805	0.999	1.198	1	0.968	0.681	1	0.873	0.981	0.918
2004	1.051	1	1.66	1	0.898	1.026	0.793	1	1.033	1.469	0.964	0.919	1.093	1.049
2005	1.044	1	0.894	1	1.428	0.997	1	1	1	1	1.037	1.141	0.947	1.031
2006	0.859	1	0.806	1	1.097	0.905	1.023	1	1	1	1	1.056	1.108	0.985
Mean	1.006	1	0.993	1	1.017	1.01	1.01	1	1	1.01	1.023	1.001	1.018	1.007

Table A4(c): Technical Change component of Malmquist TFP Indices computed using contemporaneous technology (excluding Bihar and Kerala)

	AP	ASS	GUJ	HAR	KAR	MAHA	MP	ORR	PUN	RAJ	TN	UP	WB	mean
1985	0.962	1.038	0.998	1.128	1.04	1.005	0.837	0.752	1.1	0.795	0.94	0.953	1.038	0.962
1986	1.151	1.039	1.126	1.061	1.107	1.185	1.181	1.154	0.978	1.124	1.097	1.058	1.102	1.103
1987	0.976	0.856	1.01	1.14	0.93	0.925	0.924	0.9	1.109	0.988	1.062	1.119	0.987	0.991
1988	0.962	0.902	0.974	1.199	0.999	0.905	0.91	1	1.387	1.031	0.899	1.066	0.957	1.007
1989	0.997	0.911	1.01	0.881	0.986	0.95	1.127	1.192	0.769	1.095	1.123	0.922	1.001	0.991
1990	1.055	1.062	1.053	1.318	0.952	1.04	1.035	1.025	1.187	1.052	1.008	1.147	0.936	1.063
1991	1.021	0.844	1.047	0.863	0.941	0.995	0.879	0.79	0.989	1.088	1.084	0.928	0.958	0.952
1992	1.038	1.01	1.03	1.159	0.947	0.953	1.104	1.156	1.085	0.897	0.99	1.069	0.946	1.027
1993	1.057	1.144	1.042	1.015	1.036	1.04	0.917	0.844	1.022	0.979	1.213	1.18	1.022	1.035
1994	0.869	0.787	0.894	0.911	1.019	0.822	0.973	0.938	0.971	0.935	0.782	0.704	0.83	0.875
1995	1.196	1.234	1.134	0.991	1.069	1.285	1.009	0.843	1.081	1.072	1.338	1.388	1.253	1.136
1996	0.888	0.912	0.954	0.971	0.988	0.892	1.061	1.292	1.001	0.93	0.878	0.993	0.945	0.972
1997	0.93	1.093	0.932	1.047	1.05	1.145	0.871	0.769	1.165	0.984	0.718	0.749	1.117	0.955
1998	1.134	0.912	1.027	0.937	1.022	0.967	1.031	1.073	0.936	1.069	1.243	1.074	0.952	1.025
1999	1.037	0.926	1.043	1.005	1.085	0.973	0.972	1.003	1.055	1.078	1.125	1.043	0.921	1.019
2000	1.049	0.907	1.025	1.337	1.075	1.029	0.925	0.844	1.187	0.897	1.043	1.23	1.035	1.036
2001	0.859	1.431	0.828	0.903	0.987	1.008	1.035	1.084	1.085	0.965	0.79	0.896	0.886	0.97
2002	0.961	0.959	0.989	1.036	1.016	1.039	1.066	1.057	1.062	1.409	0.96	0.966	1.062	1.04
2003	0.964	0.96	1.1	1.079	1.035	1.021	1.035	1.15	1.042	0.851	0.855	1.26	0.897	1.013
2004	0.874	0.997	0.933	1.086	0.973	0.904	0.935	0.784	1.418	1.224	0.871	0.836	1.033	0.977
2005	1.183	1.091	1.037	1.128	0.988	1.034	1.098	1.212	1.449	0.926	1.249	1.136	0.99	1.11
2006	1.064	0.998	0.97	0.965	1.016	1.013	0.884	0.867	1.294	0.911	1.195	0.84	1.053	0.998
Mean	1.006	0.992	1.005	1.046	1.011	1.001	0.987	0.975	1.096	1.006	1.007	1.012	0.993	1.01