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Total Factor Productivity Growth of *Jowar* and *Bajra* in India: A Comparative Analysis Using Different Methods of TFP Computation§

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Abstract

Jowar and *bajra* are the two main coarse cereals in India and are cultivated in regions with permanent geographical and climatic impediments. In this study, the total factor productivity (TFP) growth of *jowar* and *bajra* has been estimated using three different methods, viz. Solow index method, Törnqvist-Theil index method and the Malmquist index method. The first two methods impose certain theoretical restrictions while calculating TFP growth. These restrictions can be addressed by using the third method, viz. the Malmquist index method. *Jowar* and *bajra* being rainfed crops, rainfall has been considered as one of the inputs in the production of these coarse cereals in the Malmquist index method. Hence, it is argued that on a number of counts, the contemporaneous Malmquist index method of TFP measurement could be more preferable as it gives reliable TFP estimates.

Key words: *Jowar, bajra*, total factor productivity, Solow index method, Törnqvist-Theil index method, Malmquist index method

JEL Classification: D24, Q12

Introduction

Coarse cereals constituted around 23 per cent[1] of total gross cropped area in India in the year 2009-2010. Sorghum or *jowar* (*Sorghum bicolor* L.) and pearl millet or *bajra* (*Pennisettum typhoides* L.), the two major coarse cereals cultivated in India, accounted for nearly 28 per cent and 32 per cent of total coarse cereals acreage, respectively, during this period. These being hardy crops, are able to withstand harsh agro-ecological environment, and are primarily cultivated in the rainfed arid regions of India. Across the major coarse cereals producing states of Maharashtra, Andhra Pradesh, Karnataka, Gujarat and Rajasthan, *jowar* and *bajra* constitute, on average, 50 per cent of the total cereals consumption. Coarse cereals offer food security to both humans and livestock. Basavaraj *et al.* (2010) and Rao *et al.* (2010), however, note that consumption of *jowar* and *bajra* as food has declined in recent years in both urban and rural areas due to various reasons, with concomitant increase in their usage in the non-food industries. They argue that due to favourable government policies towards distribution of low-cost wheat and rice through the Public Distribution System (PDS), consumers of *jowar* and *bajra* in the rural areas as well are shifting towards rice and wheat[2]. They find

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[1] Estimates based on data available from *Agricultural Statistics* at a Glance (GoI, 2011)

[2] This fact has been established in Chand and Kumar (2002) and Khera (2011).

that *jowar* and *bajra* are being increasingly used in potable alcohol industries, starch industries, poultry feed, etc.

The arid and semi-arid regions are characterized with high moisture stress, low soil fertility, saline soils and lack of assured irrigation facilities (Nagaraj *et al*., 2011). As such, water-intensive crops like wheat and paddy are not suitable to cultivate in these regions. Therefore, farmers in the arid regions have to depend upon cultivating *jowar* and *bajra* for their subsistence. Besides, under the arid and semi-arid conditions, *jowar* and *bajra* are important sources of fodder and forage for livestock. Thus, coarse cereals like *jowar* and *bajra* constitute important crops, especially for the marginalized households. Therefore, increasing productivity of *jowar* and *bajra* becomes important for increasing the welfare of poor people in these regions.

There are a few studies which have documented agricultural productivity in India as a whole (Dholakia and Dholakia, 1993; Desai and Namboodiri, 1997). There are also studies on crop specific productivity growth. The total factor productivity (TFP) growth of *jowar* and *bajra* has been estimated in some studies like Janaiah *et al.* (2005) and Kumar and Mittal (2006). Both these studies are based on almost same time periods, and have used the same methodology of productivity measurement, and same data, but have reported different results for TFP growth of *jowar* and *bajra*. However, we may note that Janaiah *et al.* did not follow chain index while computing input, output and TFP index. For example, for *bajra*, Janaiah *et al.* (2005) find a TFP decline of 0.8 per cent in Rajasthan, whereas Kumar and Mittal (2006) find a positive TFP growth of 1-2 per cent in Rajasthan. Similarly, in Haryana, during the same period, Janaiah *et al.* (2005) find a high TFP growth of 4 per cent in *bajra* production, whereas, Kumar and Mittal (2006) find no change in the TFP growth of *bajra* during this period. These variations in results across different studies are not limited to *jowar* and *bajra* only, but are found in studies of other crops also, may be because of similar estimation errors. For example, in estimating the TFP growth of rice in India, Janaiah *et al.* (2006) have reported TFP growth of 4.01 per cent in the states of Bihar, Odissa, Assam and West Bengal combined. In contrast to this, Kumar and Rosegrant (1994) have found TFP growth in the eastern region (Bihar, Odissa, Assam and West Bengal) as only 0.36 per cent for a similar period.

A reason for these differences may be that in the Cost of Cultivation Scheme, the price data of inputs for various crops are available from 1980s onwards and are derived by dividing the value of inputs by their quantity. Secondly, in the Cost of Cultivation Scheme, data on inputs like irrigation and machine labour are given in value terms. Thirdly, the above studies have not explicitly mentioned (except in Janaiah *et al*., 2006) what price indices they have used to deflate these two variables, if at all. Fourthly, none of the studies has taken rainfall into account in their analysis.

To address the shortcomings mentioned above, this study has measured TFP growth of *jowar* and *bajra* using three different methods, viz. Solow index method, Törnqvist-Theil index method and Malmquist index method. Though structural changes due to economic reforms in India started from 1991 onwards, it is widely held that the effects of these reforms were noticed from the mid-1990s. We have taken the break-point at 1995 for all the three methods in order to see the changes in TFP growth during the pre-reform and post-reform periods.

Data and Methodology

This study is based on data compiled under the Comprehensive Scheme for the Study of Cost of Cultivation of Principal Crops in India (GoI a, various years). This provides information on crop-specific state-level time series data on quantities and prices of farm yield and inputs used. Among jowar-producing states, fairly continuous production data are available for four states, viz. Andhra Pradesh, Karnataka, Madhya Pradesh and Maharashtra. The time period for *jowar* was taken from 1984 to 2006. Similarly among *bajra*-producing states, fairly continuous production data are available for three states, viz. Gujarat, Haryana and Rajasthan. The time period for study of *bajra* was taken from 1981 to 2006. For each of these two crops, seven major inputs considered are: seed, fertilizer, manure, human labour, animal labour, machine labour and irrigation. Rainfall as an input was introduced only in Malmquist index method. The variables machine labour and irrigation are available only in value terms. Machines typically consist of tractors which run on diesel. Irrigation is usually carried out through diesel or electric pump-sets. Therefore, an index was constructed (taking 1995-96 as the base year) for both machine labour and irrigation expenditure by deflating the variables by the Fuel and Light index available from the Consumer Price Index Numbers for Agricultural and Rural Labourers in India (GoI b, various years). The price data availability varies across states. For most of the states under consideration, the price data are available from 1981 onwards. Therefore, for comparisons of measures of productivity across states, a uniform time period was considered.

The rainfall plays an important role in the production of *jowar* and *bajra*. And average annual rainfall has been included as one of the factors affecting TFP of the agricultural sector in some studies (Desai and Namboodiri, 1997). But, in the crop-specific studies, rainfall received by a particular crop is difficult to estimate. In order to measure the share of rainfall received by each of these two crops, we constructed a rainfall index by constructing an area weight for *jowar* and *bajra* by dividing the gross cropped area under these crops by the total gross cropped area and then multiplying this ratio with the total amount of rainfall received by that particular state in a given agricultural year. Since all other inputs considered in this study were in per hectare terms, we divided this value by the gross cropped area of *jowar* and *bajra*. Hence, the rainfall index may be represented as the ratio of rainfall received to the total gross cropped area. Thus, the rainfall index for *jowar* in the *i*th state for the *j*th year is given by:

$$Rainfall\ Index_j^i = \frac{\left(\frac{Jowar\ gross\ cropped\ area}{Total\ gross\ cropped\ area}\right) \times Rainfall_j^i}{Jowar\ gross\ cropped\ area}$$

$$= \frac{Rainfall_j^i}{Total\ gross\ cropped\ area}$$

The data on gross cropped area were obtained from *Economic Intelligence Service* (CMIE, various years). State-wise rainfall data were taken from the *Fertiliser Statistics* (FAI, various years).

The total factor productivity (TFP) being the ratio of growth of output to all the factors involved in the production process, a preferred concept is being followed in this study. To estimate TFP change, we have considered three different methods, viz. Solow index method, Törnqvist-Theil index method and Malmquist index method. All three methods have their own merits and demerits. However, the Solow index method and Törnqvist-Theil index method impose certain theoretical restrictions. A criticism of these methods of productivity measurement is that they assume a competitive equilibrium in the factor markets, i.e. factors are compensated according to their marginal products. This is a strong assumption as most of the agricultural inputs in India, such as fertilisers and irrigation, are highly subsidized by the government. In such a case, it is highly unlikely that input prices are determined competitively in the factor market. This may lead to biased productivity estimates. Another criticism is that the method assumes certain production functions and it may lead to biased results. Both are non-frontier approaches, i.e. production units are assumed to behave optimally and therefore, they always operate on the frontier. Thus, any change in the TFP index will only reflect shifts in the production frontier. Inferences on technical efficiency, which is a measure of movement towards the frontier, cannot be estimated using this procedure. Another important criticism is that the residual may reflect factors other than technical change, e.g. changes in capacity utilization between periods due to demand-side or supply-side fluctuations in the availability of electricity and other inputs.

Technical efficiency reflects the firm's ability to produce highest possible level of output given a set of inputs and technology. The Malmquist total productivity index exploits this concept and decomposes productivity changes into changes in efficiency (catching-up) and changes in technology (innovation). Caves *et al.* (1982) developed the Malmquist productivity index as the ratio of distance functions. The distance function is defined as a functional representation of multiple-output, multiple-input technology which requires data on only input and output quantities. Hence, the Malmquist index is a non-parametric approach to productivity measurement. Färe *et al.* (1994) have applied linear programming to construct the distance functions that underlie the Malmquist index. Since this index is constructed using distance functions, it only requires data on quantities of output(s) and inputs. Hence, price information is not required. Due to this reason rainfall as an input may be accounted for while measuring TFP growth of *jowar* and *bajra.*

Empirical Results

Jowar TFP Growth

A comparison of TFP growth of *jowar* across the three methods, reveals wide variations in TFP growth

Table 1. *Jowar*: TFP growth indices based on various measures, 1984-2006

State	Solow Index			Tornqvist Index			Malmquist Index		
	1984-1995	1995-2006	1984-2006	1984-1995	1995-2006	1984-2006	1984-1995	1995-2006	1984-2006
Andhra Pradesh	-0.017	0.033	0.008	1.048	0.89	0.966	1.036	1.013	1.025
Karnataka	-0.056	-0.034	-0.045	0.873	0.927	0.899	0.938	0.977	0.957
Madhya Pradesh	-0.002	0.012	0.005	0.85	0.96	0.903	1.038	1.036	1.037
Maharashtra	0.018	0.016	0.017	0.917	0.953	0.935	0.975	0.929	0.952

rates. The magnitudes of TFP growth are different for all the three indices (Table 1). Andhra Pradesh has shown a positive TFP change according to two out of the three techniques used. However, this TFP increase in Andhra Pradesh according to Solow index, is reported to be 0.8 per cent and according to Malmquist index is 2.5 per cent. But, according to the Törnqvist index, there has been a TFP decline of 3.4 per cent in Andhra Pradesh. This shows that if we use only Solow and Törnqvist indices then there may be an issue of biases in the TFP results. Karnataka, on the other hand, has shown a declining TFP growth in all the three techniques. Studies on TFP estimates on *jowar* like by Chand *et al.* (2011), Kumar and Mittal (2006) and Janaiah *et al.* (2005) find Andhra Pradesh to have a positive TFP growth rate and Karnataka with a negative TFP growth rate. Madhya Pradesh moves from being a state with positive TFP in Solow index and Malmquist index, to a state with negative TFP in the Törnqvist index method. For a similar time period, using Törnqvist method, however, Kumar and Mittal (2006) have found Madhya Pradesh with no changes in TFP for *jowar* cultivation. Janaiah *et al.* (2005) have reported an increase in TFP of 1.8 per cent in Madhya Pradesh. Maharashtra, on the other hand, has a negative TFP according to Törnqvist and Malmquist methods, but a positive TFP according to Solow method. Similar to Madhya Pradesh, Kumar and Mittal (2006) have reported no change in TFP for Maharashtra, but Janaiah *et al.* (2005) have found an increase in TFP for Maharashtra.

By shifting the break points for the Malmquist index method from 1995 till 2000 (Figure 1), we see that in Andhra Pradesh there has been a steady rise in *jowar* TFP growth in the post-reform periods. In

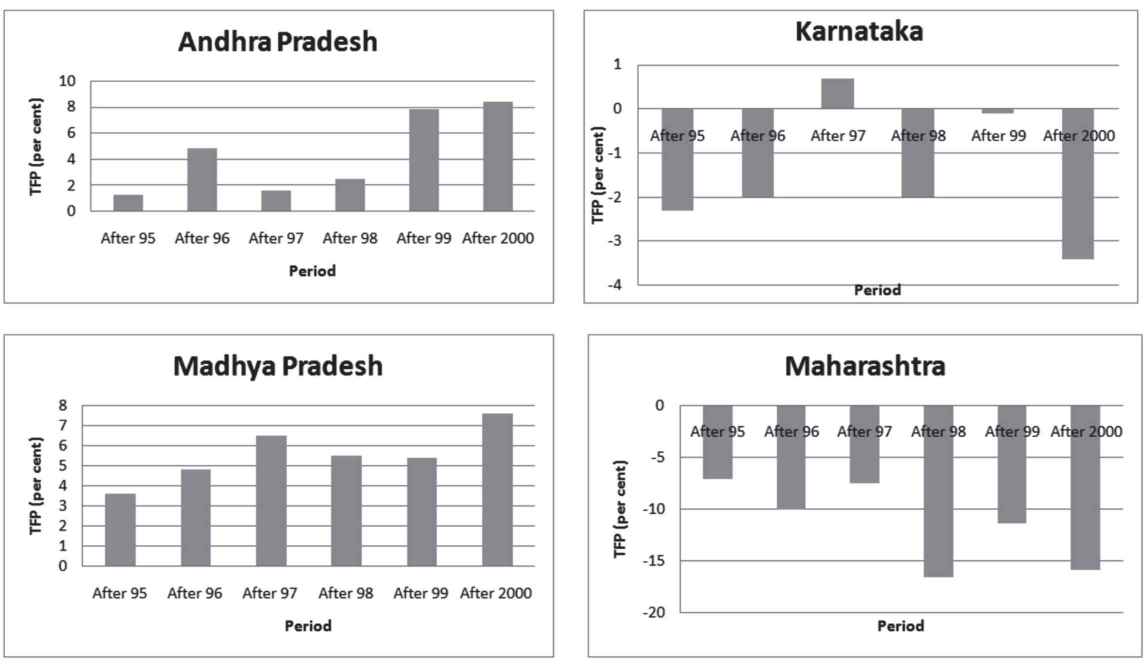

Figure 1. *Jowar*: Shifting break points for Malmquist index, 1995 to 2000

Table 2. ***Bajra*: TFP growth indices based on various measures, 1981-2006**

State	Solow Index			Tornqvist Index			Malmquist Index		
	1981-1995	1995-2006	1981-2006	1981-1995	1995-2006	1981-2006	1981-1995	1995-2006	1981-2006
Gujarat	0.008	0	0.004	0.924	0.979	0.948	1.001	0.996	0.998
Haryana	-0.067	0.033	-0.017	0.931	0.99	0.956	0.964	1.037	0.995
Rajasthan	0.004	-0.021	-0.009	0.906	0.997	0.945	0.989	1.09	1.033

Karnataka, there has been a constant dip in TFP in the post-liberalization period, except if we take 1997 as the break point. Similar to Andhra Pradesh, in Madhya Pradesh also, there has been a rise in TFP growth in the post-reform period. However, in Maharashtra there has been a decline TFP in the post-reform period, which increases if we shift the break point from 1995 to 2000. These results indicate that we do equally well by taking 1995 as the break point in order to see changes in TFP, where we find that Andhra Pradesh and Madhya Pradesh are the two states which have a positive TFP growth of *jowar* production in the post-reform period. And, Karnataka and Maharashtra are the two states witnessing a decline in TFP in the post-reform period.

Bajra TFP Growth

The results of *bajra* productivity have also shown wide variations across all the three methods of TFP measurement (Table 2). Gujarat has shown a positive TFP growth according to Solow index, but has a negative TFP growth according to Törnqvist and Malmquist indices. This is in contrast to the findings by Janaiah *et al.* (2005), wherein Gujarat has been found to have a positive TFP growth of 1 per cent according to Törnqvist method. Kumar and Mittal (2006), on the other hand, have reported no change in TFP for Gujarat in *bajra* cultivation during a similar period. Rajasthan has performed well according to Malmquist index, but has a depressing TFP according to Solow and Törnqvist indices. Janaiah *et al.* (2005) as well as Kumar and Mittal (2006) have reported Rajasthan to have a high positive TFP growth rate. In our study, Haryana is reported to have a negative TFP growth, by all the three methods, however, the magnitudes are different — 1.7 per cent according to Solow index, 0.5 per cent according to Törnqvist index, and 4.4 per cent according to the Malmquist.

By shifting the break points for the Malmquist index method from 1995 till 2000 (Figure 2), we see that in Gujarat, the post-reform TFP growth of *bajra*

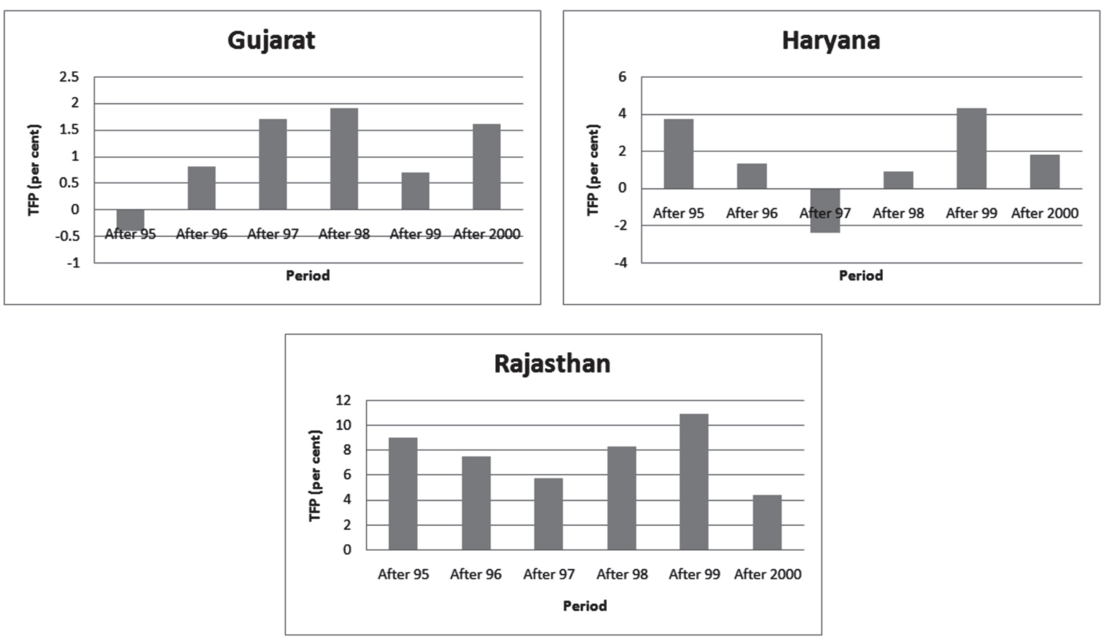

Figure 2. ***Bajra*: Shifting break points for Malmquist index, 1995 to 2000**

continues to rise if we take 1996 as the break point. In Haryana, there is a rise in TFP if we take 1996 as the break point. However, if we take 1997 as the break point, then we see that TFP declines in the post-reform period in Haryana. But, for the remaining consecutive break points, TFP shows a positive growth. In Rajasthan, there is a steady rise in *bajra* TFP growth rate for all the break points. These results indicate that, except for Gujarat, there is a rise in *bajra* TFP growth in Haryana and Rajasthan in the post-reform period, similar to the result by taking 1995 as the break point. For Gujarat, it may be inferred that any rise in TFP growth for the post-reform period might have occurred after 1995.

Similar to the study in *jowar* productivity change, the results show a substantial different picture of *bajra* TFP changes according to the three TFP methods used in this study. However, as has been clarified earlier, there are certain theoretical restrictions imposed by the Solow and the Törnqvist index methods. This illustrates the fact that TFP estimates based on these two methods may give biased results and hence are less preferred.

Conclusions and Policy Implications

This study has analysed the TFP growth of two major widely-cultivated major coarse cereals in India, viz. *jowar* and *bajra* from 1980s to 2006. Since these two cereal crops are the staple diet of poor households in the dry regions and are also the source of fodder for the livestock, increasing their productivity is important. The TFP growth of *jowar* and *bajra* has been measured using three different methods, viz. Solow index method, Törnqvist-Theil index method and Malmquist index method. The first two methods impose certain theoretical restrictions while calculating the TFP growth. These restrictions may be overcome by using the third method, viz. Malmquist index method. As such, TFP estimates based on the first two methods may give us biased results. Thus, it has been argued that on a number of counts, the contemporaneous Malmquist index method of TFP measurement might be more preferable as it gives reliable TFP estimates.

Jowar productivity in Andhra Pradesh is encouraging according to two of the three methods of TFP measurement applied in this study. Karnataka has a negative TFP growth rate according to all the three methods. These findings are similar to the available literature on *jowar* TFP measurements. This is an encouraging inference as all the three methods have given similar results. However, TFP growth rates do vary across these methods. In *bajra* cultivation, Rajasthan has a positive TFP growth according to Törnqvist and Malmquist methods, but a negative TFP growth according to Solow method. Gujarat and Haryana have shown a positive TFP growth according to one of the methods and a negative TFP growth according to the other two methods.

Jowar and *bajra* are low-value crops and are cultivated in regions with traditional impediments like moisture-deficient soils. Hence, investments made in modern technologies for these crops become risky and uncertain. Demands for *jowar* and *bajra* are region- and economic class-specific, but there is evidence that demand for these cereal crops is rising partially for non-food purposes like poultry feed, industrial uses, etc. (Basavaraj *et al.*, 2010; Rao *et al.*, 2010). Therefore, to address the constraints involved in cultivation of these two crops and to increase its potential for alternative uses, there is a need to raise their production through low cost technologies.

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References

Basavaraj, G., Parthasarathy Rao, P., Bhagavatula, S. and Ahmad, W. (2010) Availability and utilization of pearl millet in India. *Journal of SAT Agricultural Research*, **8**: 1-6.

Bhushan, Surya (2005) Total factor productivity growth of wheat in India: A Malmquist approach. *Indian Journal of Agricultural Economics*, **60**(1): 32-48.

Caves, Douglas W., Christensen, Laurits R. and Diewert, W. Erwin (1982) The economic theory of index numbers and the measurement of input, output and productivity. *Econometrica*, **50**(6): 1393-1414.

CMIE (Centre for Monitoring Indian Economy) (various issues) Agriculture, Economic Intelligence Service, Mumbai.

Chand, Ramesh and Kumar, Praduman (2002) Long-term changes in coarse cereal consumption in India: Causes and implications. *Indian Journal of Agricultural Economics*, **57**(3): 316-325.

Chand, Ramesh, Kumar, Praduman and Kumar, Sant (2011) *Total Factor Productivity and Contribution of Research Investment to Agricultural Growth in India*. Policy Paper 25. National Centre for Agricultural Economics and Policy Research, New Delhi.

Coelli, Tim J. (1996) *A Guide to DEAP Version 2.1: Data Envelopment Analysis (Computer) Program*. Centre for Efficiency and Productivity Analysis (CEPA), Working Papers 8/96, Department of Econometrics, University of New England, Armidale.

Desai, Bhupat M. and Namboodiri, N.V. (1997) Determinants of total factor productivity in Indian agriculture. *Economic and Political Weekly*, **32**(52): A165-A171.

Dholakia, Ravindra H. and Dholakia, Bakul H. (1993) Growth of total factor productivity in Indian agriculture. *Indian Economic Review*, **28**(1): 25-40.

Färe, Rolf, Grosskopf, Shawna, Norris, M. and Zhang, Z. (1994) Productivity growth, technical progress and efficiency change in industrial countries. *American Economic Review*, **84**(1): 66-83

FAI (Fertiliser Association of Indi) (various issues) *Fertiliser Statistics of India*, New Delhi.

GoI (Government of India) (2011) *Agricultural Statistics at a Glance*. Directorate of Economics and Statistics, Ministry of Agriculture and Co-operation, New Delhi.

GoI (Government of India) (2011a, various issues) *Cost of Cultivation of Principal Crops in India*. Directorate of Economics and Statistics, Ministry of Agriculture and Co-operation, New Delhi.

GoI (Government of India) (2011b, various issues) *Consumer Price Index Numbers for Agricultural & Rural Labourers in India*. Annual Report, Labour Bureau, Ministry of Labour, Shimla/Chandigarh.

Janaiah, Aldas, Achoth, Lalith and Bantilan, Cynthia (2005) Has the green revolution bypassed coarse cereals? The Indian experience. *Journal of Agricultural and Development Economics*, **2**(1): 20-31.

Janaiah, Aldas, Hossain, Mahabub and Otsuka, Keijiro (2006) Productivity impact of the modern varieties of rice in India. *The Developing Economies*, **XLIV**(2): 190-207.

Khera, Reetika (2011) India's public distribution system: Utilisation and impact. *Journal of Development Studies*, **27**(7): 1038-1060.

Kumar, Praduman and Mittal, Surabhi (2006) Agriculture productivity trends in India: Sustainability issues. *Agriculture Economics Research Review*, **19**: 71-88.

Kumar, Praduman and Rosegrant, Mark W. (1994) Productivity and sources of growth for rice in India. *Economic and Political Weekly*, **29**(53): A183-A188.

Kumar, Praduman and Mruthyunjaya (1992) Measurement and analysis of productivity growth in wheat. *Indian Journal of Agricultural Economics*, **47** (7): 451-458.

Nagaraj, N., Basavaraj, G. and Parthasarathy Rao, P. (2011) *Policy Brief on Future Outlook and Options for Target Crop: The Sorghum and Pearl Millet Economy of India*. Policy Paper for HOPE Project Milestone 1.1.5 in South Asia, International Crops Research Institute for the Semi-Arid Tropics, Patancheru, Andhra Pradesh.

Rao, P. Parthasarthy, Birthal, P.S., Reddy, Belum V.S., Rai, K.N. and Ramesh, S. (2006) Diagnostics of sorghum and pearl millet grains-based nutrition in India. *International Sorghum and Pearl Millet Newsletter*, **4**: 93-96.

Rao, P. Parthasarthy, Basavaraj, G., Ahmad, W. and Bhagavatula, S. (2010) An analysis of availability and utilization of sorghum grain in India. *Journal of SAT Agricultural Research*, **8**: 1-8.

Solow, Robert M. (1957) Technical change and the aggregate production function. *The Review of Economics and Statistics*, **39**(3): 312-320.

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Appendix 1

Solow Index Method

$$\ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = \ln\left(\frac{y_t}{y_{t-1}}\right) - \sum_i \beta_{i,t} \ln\left(\frac{x_{i,t}}{x_{i,t-1}}\right)$$

where, y_t is the output in period t and $x_{i,t}$ is the i^{th} input used in period t. The symbol β_i denotes the factor share of the input $x_{i,t}$ such that $\beta_i = \frac{w_i x_i}{\sum w_i x_i}$, where w_i is the income of factor x_i. There is constant returns to scale given by $\Sigma\beta_i = 1$. This ensures that output elasticity is equal to input shares in the total cost TFP_t, represents total factor productivity (TFP) or that part of output growth which cannot be explained by growth in any of the inputs.

Törnqvist-Theil Index Method

$$TFPG = ln\left(\frac{TFP_t}{TFP_{t-1}}\right) = ln\left(\frac{y_t}{y_{t-1}}\right) - \sum_j \frac{1}{2}(S_{jt} + S_{jt-1}) ln\left(\frac{x_{jt}}{x_{jt-1}}\right)$$

where, y_t and y_{t-1} represent the output in periods t and t-1, respectively. S_{jt} is the factor share of input x_{jt} in period t, and S_{jt-1} is the factor share of input x_{jt-1} in period t-1.

Malmquist Index Method

$$M_o(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{D_o^{t+1}(x^{t+1}, y^{t+1})}{D_o^t(x^t, y^t)} \times \left\{\left(\frac{D_o^t(x^{t+1}, y^{t+1})}{D_o^{t+1}(x^{t+1}, y^{t+1})}\right) \times \left(\frac{D_o^t(x^t, y^t)}{D_o^{t+1}(x^t, y^t)}\right)\right\}^{1/2}$$

Here, $D_o^t(x^t, y^t)$ is the distance function for time period t with respect to the technology available at the current period t and input-output combinations of period t. Note that this distance function value $D_o^t(x^t, y^t) = \theta \leq 1$, or else it will lie outside the production frontier. This is the smallest factor by which the output vector y^t could be increased when making production as technically efficient as possible, based on the input vector x^t. Similarly, for the others. The first-term on the right hand side shows 'efficiency change' and the term within the braces show 'technical change'. Improvements in productivity are shown by a value greater than 1, whereas deterioration and *status quo* are shown by a value less than and equal to 1, respectively. Similarly, for the efficiency change index part and technical change index part. DEAP *Version 2.1* of Coelli (1996), was used to derive the Malmquist Total Productivity Index and its various components.

Appendix Table 1a. *Jowar*: Output index, input index, efficiency change, technological change and TFP change

State	Solow Index			Tornqvist Index			Malmquist Index		
	Output index	Input index	TFP index	Output index	Input index	TFP index	Efficiency change	Technological change	TFP change
Andhra Pradesh	0.007	-0.001	0.008	1.034	1.070	0.966	1.0	1.025	1.025
Karnataka	-0.041	0.004	0.045	0.983	1.093	0.899	0.989	0.967	0.957
Madhya Pradesh	-0.005	-0.01	0.005	1.016	1.124	0.903	1.0	1.037	1.037
Maharashtra	0.016	-0.001	0.017	1.026	1.097	0.935	1.0	0.952	0.952

Appendix Table 1b. *Bajra*: Output index, input index, efficiency change, technological change and TFP change

State	Solow Index			Tornqvist Index			Malmquist Index		
	Output index	Input index	TFP index	Output index	Input index	TFP index	Efficiency change	Technological change	TFP change
Gujarat	0.002	-0.002	0.004	1.008	1.063	0.948	0.999	1.0	0.998
Haryana	-0.022	-0.005	0.017	1.030	1.077	0.956	1.0	0.995	0.995
Rajasthan	-0.001	0.008	0.009	1.037	1.097	0.945	1.0	1.033	1.033