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Inter-state variation in technical efficiency and total factor productivity of India's livestock sector

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Abstract During last two and half decades (1990-2016), the Total Factor Productivity (TFP) of livestock sector has grown at an annual rate of 3.9%. However, there are significant variations in it across states. It is estimated very high in Tamil Nadu (8.7%), Andhra Pradesh (7.6%) & Odisha (7.6%) and extremely low in Jammu & Kashmir (0.6%), Himachal Pradesh (-0.4%) and Bihar (-4.3%). Interestingly, TFP growth has been driven by technical change. The estimates of scale efficiency indicate scope of raising output by about 30% even at the existing levels of input-use. The findings suggest the need for greater investment in animal science research and development, especially in the states that have poorly performed on technological front.

Keywords Livestock, TFP, technical efficiency, scale efficiency, returns to scale

JEL Codes O3, Q1,

Economic liberalization and globalization have opened up significant opportunities for market-led growth of livestock sector. The demand for livestock products has been witnessing a continuous surge (Gandhi and Zhou 2010). By 2030, global demand for milk and meat is expected to rise by 33% and 19%, respectively above their levels in 2015-17 (FAO 2018). This presents an opportunity for alleviation of poverty and improving nutritional security. The development of livestock sector will have direct or indirect impacts on nearly 16.44 million rural households in India GoI (2020). In the past five years, India's livestock sector grew at an annual rate of 8% GoI (2019). Nevertheless, livestock production remains constrained by several factors such as the small herd size, scarcity of feeds and fodder and poor delivery of breeding and veterinary services.

India's livestock is characterised by low levels of productivity and input use. Hence, there is a need to look for the ways to enhance productivity of inputs either by the generation of new technologies or improving efficiency of input use. Crossbreeding with exotic breeds has been a prominent technology in India since the 1960s. Previous studies have documented the evidence of productivity-led growth in the crop sector (Kumar and Mruthyunjaya 1992; Kumar and Rosegrant 1994; Evenson et al.1999; Murgai 1999; Joshi et al. 2003; Kumar et al. 2004; Coelli and Rao 2005; Chand et al. 2011; Chaudhary 2012). However, similar studies for the livestock sector are scarce (Birthal et al.1999; Avila and Evenson 2010).

This study is an attempt to understand whether India's livestock sector has experienced technological progress or not. Estimation of TFP growth and its decomposition has been carried out to identify the sources of productivity growth. Along with the TFP, the measures of technical efficiency and scale efficiency for each state have also been estimated.

Methodology

TFP is a measure of the contribution of improved technologies which could be on account of research, extension, education, infrastructure and policy interventions. These factors also enhance productivity of inputs. This study uses non-parametric Malmquist index (DEA approach) to measure TFP. DEA can be either input-orientated or output-orientated. We applied the latter, since it provides a maximum proportional increase in output level with input levels held constant (Coelli and Rao 2005). The estimated technical efficiency scores remain the same, irrespective of whether we apply input-oriented or output-oriented DEA under constant returns to scale (CRS), but these vary under variable returns to scale (VRS).

Technical efficiency under CRS and VRS can be estimated by solving a linear programming problem (Ali and Seiford 1993):

$$\max_{\theta,\lambda} \theta_i$$

Subject to

$$\sum_{j=1}^{n} \lambda_j x_{kj} + e_k = x_{ki}$$

$$\lambda_j \geq 1; s \geq 0; e_k \geq 0$$

Where θ_i is the proportional increase in output for the i^{th} state, λ_j is an N × 1 vector of weights relative to efficient observations, s is the output slack, and e_k is the k^{th} input slack. By adding the convexity constraint N1'λ = 1, the CRS model can be modified into VRS DEA (Banker et al. 1984). When the values of θ and λ_i are equal to 1, and λ_j= 0, the Decision Making Unit (DMU) is said to be efficient. By contrast, when θ > 1, λ_i= 0, and $\lambda_j \neq 0$, it is inefficient.

Scale efficiency (SE) is obtained by comparing the difference between TE(CRS) and TE(VRS). If the difference lies between the two scores, that means there is scale inefficiency. SE varies from 0 to 1, where a value of 1 indicates full-scale efficiency and less than 1 indicates the presence of scale inefficiency.

SE can be calculated as follows (Coelli, 1996):

$$SE_i = \frac{TE_i^{CRS}}{TE_i^{VRS}}$$

Malmquist TFP index method

The Malmquist Productivity Index (MPI) is a measure of productivity change that relies on the distance functions. It allows estimation of multi-input and multi-output production functions without any explicit price data or any assumption regarding economic behaviour such as profit maximization or cost minimisation. The advantage of this method is its ability to decompose TFP growth into four components: (a) changes in technical efficiency over time (catching-up), (b) shifts in technology over time (technical change), (c) pure efficiency changes, (d) scale efficiency changes. Pure technical efficiency shows how the resources are managed in a production unit while scale efficiency reflects whether the production unit operates at an optimal scale or not.

The productivity change index (MPI) using technology at period *t* as reference is defined as:

$$M_0^t(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^t(x_t, y_t)}\right]$$

If we take *t+1* period technology as a reference, MPI would be:

$$M_0^{t+1}(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_0^{t+1}(x_{t+1}, y_{t+1})}{d_0^{t+1}(x_t, y_t)}\right]$$

Fare et al. (1994) specify an output-oriented geometric mean of two indices given above to avoid choosing an arbitrary period of reference.

$$M_0(x_t, y_t, x_{t+1}, y_{t+1}) = \left[\frac{d_0^t(x_{t+1}, y_{t+1}) d_0^{t+1}(x_{t+1}, y_{t+1})}{d_0^t(x_t, y_t) d_0^{t+1}(x_t, y_t)}\right]^{\frac{1}{2}}$$

MPI can further be decomposed into two components: Efficiency change and Technical change:

$$EFFCH = \left[\frac{d_0^{t+1}(x_{t+1}, y_{t+1})}{d_0^t(x_t, y_t)}\right]$$

$$TECHCH = \left[\frac{d_0^t(x_{t+1}, y_{t+1})}{d_0^{t+1}(x_{t+1}, y_{t+1})} \times \frac{d_0^t(x_t, y_t)}{d_0^{t+1}(x_t, y_t)}\right]^{\frac{1}{2}}$$

Efficiency change (EFFCH) is the efficiency change index that measures the output-oriented shift in technology between two periods. If it is greater than 1, then there is an improvement in productive efficiency, otherwise there is the degradation of the given unit. Similarly, TECHCH measures technical change between two periods. If it is greater than 1 then it means technological progress.

Data and variables

The study relies on secondary data from various published and unpublished sources. Data are collected for 16 major states for 1990-91 to 2015-16.

Value of output: Data on total value of output from the livestock sector was collected from National Accounts Statistics. The data was converted into constant (2015-16) prices using the GDP deflator.

Inputs: Three major input groups used are: feed, labour and animal stock. State-wise green fodder production was estimated using the area under green fodder. An average yield of 50 t/ha (*CSO*, 2018) was assumed. Similarly, the land under permanent pastures, cultivable wasteland, grazing land, land under miscellaneous uses were clubbed to estimate fodder availability. State-wise data on the annual value of straw and stalks was taken from the *Central Statistics Office* (CSO) and converted into constant 2015-16 prices.

To estimate the labour use in livestock production, the data on agricultural labourers and cultivators were collected from Population Census 1991, 2001 and 2011. It was assumed that one-fourth of male and three-fourth of female cultivators/agricultural labourers are engaged in livestock activities. Further, it was assumed that three women labourers are equivalent to two men labourers (Elumalai and Pandey 2005; Chand and Sirohi 2015). Interpolation was done to estimate the labour for inter-census periods.

Animal stock is the total number of cattle, buffalos, sheep, goats, pigs and poultry measured in Standard Animal Units (SAU) Sirohi et al. (2019). The data on livestock population was compiled from various rounds of livestock census from 1992 to 2019. Data for inter-census period were linearly interpolated.

Results and discussion

Technical and scale efficiency

The technical efficiency measures have been estimated for each state, both under constant returns to scale (CRS) and variable returns to scale (VRS) and summarized in Table 2. Results indicate an average technical efficiency score of 0.654 under CRS and 0.927 under VRS. Haryana, Punjab, Jammu &Kashmir (J&K), Kerala, West Bengal and Bihar are operating under full technical efficiency (CRS), while Himachal Pradesh, Uttar Pradesh and Odisha have shown full technical efficiency only under VRS. In other states, livestock output produced is much lower than the maximum level that can be achieved by using the available inputs under given technology. This implies that these states have enormous scope to improve their efficiency using the technical inputs at their disposal.

The average scale efficiency is 0.689%, which implies that the possibility of increasing output by about 30% still exists. Further analysis shows that Haryana, Punjab, J&K, Bihar, West Bengal and Kerala have an optimal level of scale efficiency under CRS. Scale-inefficient states are Uttar Pradesh, Andhra Pradesh, Karnataka, Tamil Nadu, Maharashtra, Rajasthan, Gujarat, and Madhya Pradesh. The average herd size in these states is supra-optimal, which could be reduced to reach an optimal scale. Himachal Pradesh and Odisha are the only states, operating under increasing returns to scale, exhibiting sub-optimal performance; the average herd size in these states could be increased to achieve full-scale efficiency.

Table 1 Summary statistics

Region	Mean					
	Value of output (Million Rs)	Dry fodder (Million Rs)	Green fodder (‘000 tons)	Labour (‘000 man-equivalents)	Pasture (‘000 ha)	Animal stock (SAU in ‘000)
East	20761	3445	317	5357	584	20700
North	23948	3173	21300	3734	773	14900
South	22626	1683	4600	5017	996	14400
West	29271	5283	73900	8809	3750	26000
Overall	24351	3379	26400	5628	1538	18600

Table 2 Technical and scale efficiency

State	Technical efficiency (CRS)	Technical efficiency (VRS)	Scale efficiency	Returns to scale
Haryana	1.000	1.000	1.000	Constant
Punjab	1.000	1.000	1.000	Constant
Jammu &Kashmir	1.000	1.000	1.000	Constant
Bihar	1.000	1.000	1.000	Constant
West Bengal	1.000	1.000	1.000	Constant
Kerala	1.000	1.000	1.000	Constant
Himachal Pradesh	0.588	1.000	0.588	Increasing
Odisha	0.365	1.000	0.365	Increasing
Uttar Pradesh	0.483	1.000	0.483	Decreasing
Andhra Pradesh	0.523	0.982	0.533	Decreasing
Karnataka	0.505	0.859	0.588	Decreasing
Tamil Nadu	0.59	0.842	0.701	Decreasing
Maharashtra	0.396	0.865	0.457	Decreasing
Gujarat	0.513	0.827	0.62	Decreasing
Rajasthan	0.242	0.736	0.329	Decreasing
Madhya Pradesh	0.262	0.719	0.365	Decreasing
Mean	0.654	0.927	0.689	

Total factor productivity growth

This section describes growth in TFP indices under the assumption of CRS. Rather than limiting the discussion to the direction of change in the TFP index, we have attempted to study the change in magnitude of the index in terms of growth rate as well. TFP index value of less than 1 indicates declining productivity or vice versa. For the detailed annual mean TFP indices refer to appendix Table A1. For simplifying the interpretation, average TFP growth rates have been presented in Table 3. Besides the average TFP growth rate for the period 1990 to 2016, growth rate at three sub-periods, i.e., triennium ending (TE) 1992-93, 2002-03 and 2015-16 have also been presented for a better understanding. The estimates suggest positive TFP growth in the livestock sector. Except for J&K and Bihar, all other states have witnessed a positive change in TFP growth. Although in terms of overall productivity the performance of Tamil Nadu, Andhra Pradesh and Odisha has been better (Table 3), the sub-period growth rates reflect a more realistic pattern.

In the northern region, the TFP growth has been highest for Haryana (5.6%), followed by Punjab (4.8%) and UP (3.9%). Hill states such as HP and J&K are poor performers on technological progress. TFP growth for the southern states has been positive. Tamil Nadu registered the highest growth of 8.7%, followed by AP (7.6%) while Kerala (4.9%) and Karnataka (4%) have also fared well. In the eastern region, Bihar with an average TFP growth of -0.4% is the poorest performer on technological progress. Despite being one of the agriculturally backward states, Odisha has overall high livestock productivity growth (7.6%) in the eastern region which can be attributed to the successful adoption of crossbreeding technology (Sirohi 2005). In the western region, Rajasthan has the highest TFP growth of 5.9%, followed by Maharashtra (5.5%) and Gujarat (3.4%).

An analysis by sub-period shows that in the northern region, Haryana witnessed a huge decline in its productivity growth, from an average of 6.6% to a negative of 0.3% in TE 2002-03, which recovered to reach 8.5% in TE 2015-16. Punjab has been faring well throughout, suggesting that the state has been on the path of technical progress. Uttar Pradesh, on the other hand, performed poorly initially, but has shown significant improvement later on. Jammu &Kashmir too has been able to accelerate its growth from –18.7% to 12.3% in TE 2015-16. Himachal Pradesh has

Table 3 TFP growth rate in India's livestock sector

States	TFP change (%)			
	TE 1992-93	TE 2002-03	TE 2015-16	1990-2016
Tamil Nadu	10.3	4.1	13.9	8.7
Andhra Pradesh	11.0	19.4	30.3	7.6
Odisha	12.8	5.0	2.5	7.6
Rajasthan	7.0	-12.9	17.5	5.9
Haryana	6.6	-0.3	8.2	5.6
Maharashtra	3.5	0.1	17.9	5.5
Punjab	16.0	16.1	25.0	4.8
Kerala	15.0	-2.0	0.8	4.9
Karnataka	3.5	-1.2	11.7	4.0
Uttar Pradesh	-0.9	-1.2	13.2	3.9
West Bengal	3.5	2.0	9.5	3.9
Gujarat	4.2	-1.6	5.8	3.4
Madhya Pradesh	3.5	-9.4	15.2	1.6
Himachal Pradesh	-1.9	4.4	4.6	0.6
Bihar	-17.8	3.9	9.0	-0.4
Jammu &Kashmir	-18.7	-14.9	12.3	-4.3
Mean	3.6	0.7	12.3	3.9

experienced nearly constant growth of about 4% since 2000 (Table 3).

In the southern region, Tamil Nadu is the top performer, followed by Andhra Pradesh. Kerala which was one of the best performing states in TE 1992-93 experienced a decline in productivity growth in the latter periods. Tamil Nadu and Karnataka have shown continuous improvement in productivity growth, except in TE 2002-03. In the western region, TFP growth deteriorated in the TE 2002-03. Maharashtra experienced considerable good growth after TE 2002-03. A similar trend is observed for Rajasthan, Gujarat and Madhya Pradesh.

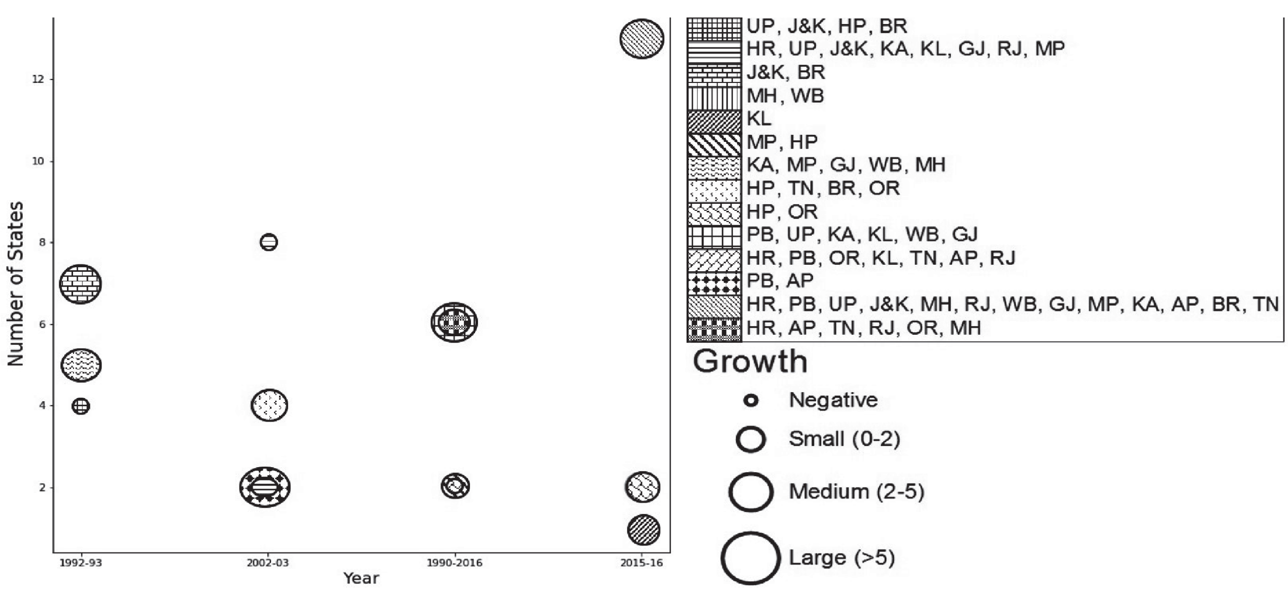

Figure 1 Trends in TFP growth rates in India's livestock sector

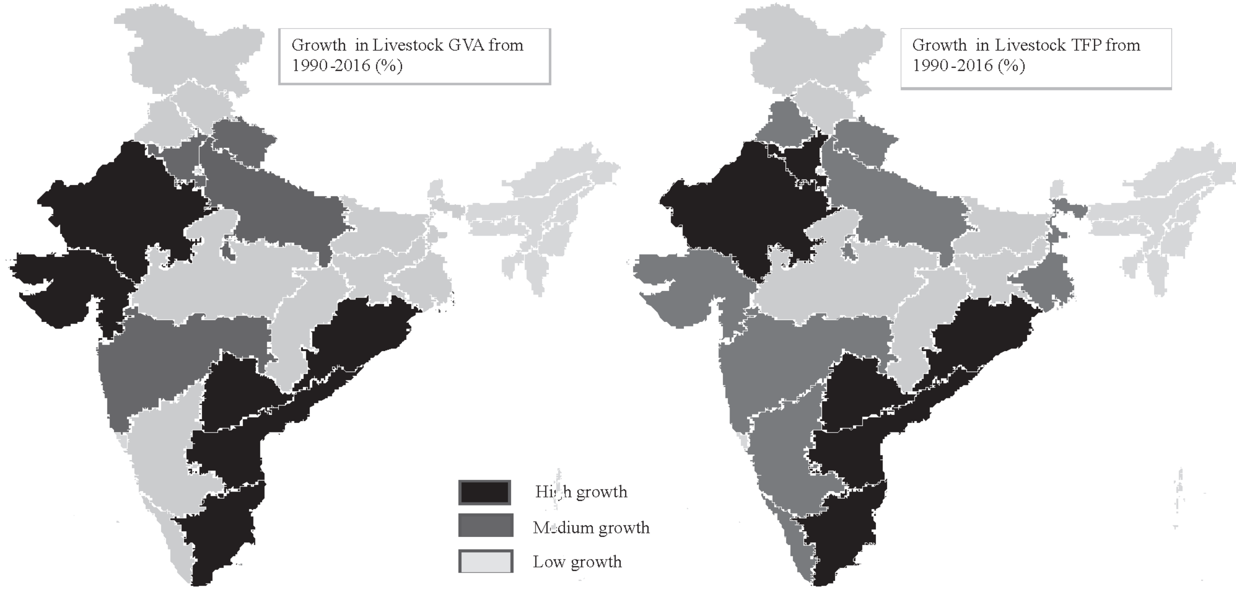

Figure 2 Congruence between growth in livestock GVA and TFP across states

In the eastern India, Bihar performed poorly during the initial period, as is evident from a highly negative growth in TE 1992-93. However, in the later periods, it recovered from sluggish growth to high growth rate of 9% in TE 2015-16. Odisha emerged as one of the top performers in overall growth, but a look at sub-period growth rates paints an altogether different picture. TFP grew at an impressive rate (12.8%) in earlier TE 1992-93 but the growth in later period drastically came down to about 2.5% in TE 2015-16. The declining trend points towards the slower technological development of the sector in recent times. West Bengal has shown positive TFP growth in all the sub-periods (Table 3).

At the national level, the average TFP growth rate in TE 1992-93 was 3.6% which declined to 0.7% in TE 2002-03 later rise to 12.3% in TE 2015-16. Further, it may be inferred from the findings that the TFP in livestock sector in most states has shown improvement over time.

A visual comparison of the states' growth in the livestock gross value added (GVA) and TFP in figure 2 shows a congruence between the two. The states having high TFP growth also have high growth in livestock GVA.

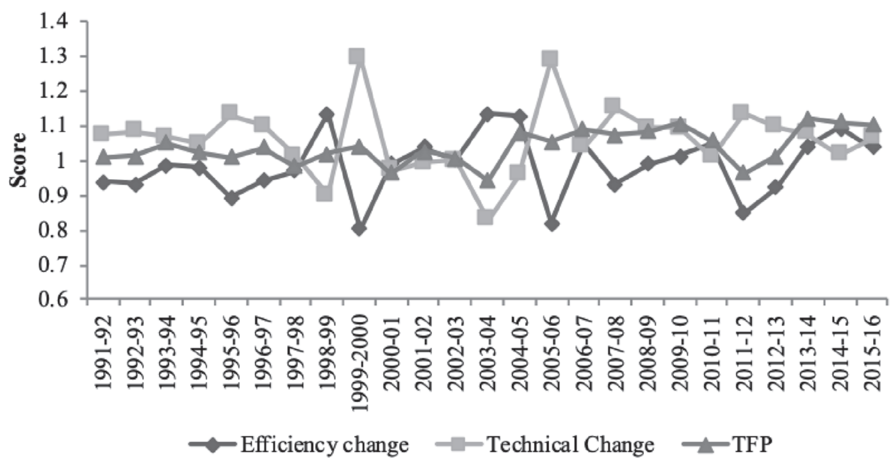

Figure 3 Components of TFP change: Technical and efficiency change

Sources of productivity growth

TFP is not synonymous with technological progress (Kalirajan and Shand 1997). TFP growth can be further decomposed into technical change and efficiency change. The decomposition analysis is essential to understand the sources of productivity growth whether it is a result of technical progress/change or change in efficiency due to improvement in human capital. Efficiency change or efficiency improvement measures the relative deviation of each state from its corresponding frontier. The technical change component measures the overall movement of frontiers over the time period.

The mean efficiency score as well as technical change component have been summarised state-wise in Table 4 and for detailed component wise indices refer Table A3 and A4 in the appendix. The mean efficiency scores for most of the selected states are ≤ 1, revealing either a constant or declining pattern in efficiency component. The technical progress is identified as the main driver of productivity growth in Haryana, Punjab, Rajasthan, West Bengal and Kerala, as is evident from the respective mean technical change score >1 and a constant mean (efficiency score=1). Odisha is the only state where both the components have a mean score of more than 1. All other states have suffered decline in the efficiency, while the technical change recorded a steady growth. Livestock productivity growth at the national level is mainly driven by technical progress (average score 1.057). The technological change is embodied in the form of crossbreeding of local non-descript cattle with exotic germplasm and preventive vaccination. However, the gains obtained from crossbreeding technology have not been evenly distributed across states. Studies also point towards the weak link between research and technology transfer due to the absence of a well-developed extension system for the livestock (Rathod et al. 2018; Abed and Acosta 2018).

Declining efficiency is a serious concern which could be mainly attributed to poor quality feed and fodder availability and high feed prices which alone constitutes about 60-70% cost of milk production. The existing evidence suggests that Indian livestock sector is heavily reliant on agricultural crop residues for their fodder requirement, which doesn't suffice for the nutritional requirement of the animal (Dikshit and Birthal 2010), thus limiting efficiency improvement. Prevalent fodder scarcity makes development and adoption of high yielding and multi-cut hybrids/varieties of fodder a crucial research agenda for livestock development. Some fodder varieties such CSH-20, CSH-24 (suitable for all India) and CoFS-29 (TN and irrigated zone) of sorghum and UPC 628 of cowpea (suitable for northeast, northwest and hilly zone) during Kharif season need wider adoption. Berseem varieties such as: BL-42 (suitable for northern states) and JHB-146 (North West and central zone) and Oats varieties such as: JHO 99-2 (Northwest and northeast zone), RO-19 (all oat growing areas), OL-125 (Northwest and central zone) are suitable during Rabi season. Most of the livestock owners in India are small landholders and require institutional support in terms of credit and proven livestock technology. Poor access to credit discourages adoption of improved technologies and quality inputs. Further, the credit linked insurance scheme although provides protection against risk, it adds to the cost of borrowing (Rajeswaran et al. 2014). Information asymmetry is also one of the constraining factors.

Besides, there are some exogenous factors such as low milk prices and market volatility which might constrain

Table 4 Estimates of technical change and efficiency change in Indian livestock sector-1990-2016

State	Efficiency change	Technical change
Haryana	1.000	1.056
Punjab	1.000	1.048
Uttar Pradesh	0.983	1.056
Himachal Pradesh	0.943	1.067
Jammu &Kashmir	0.935	1.023
Andhra Pradesh	0.988	1.089
Karnataka	0.974	1.067
Kerala	1.000	1.049
Tamil Nadu	0.987	1.101
Bihar	0.980	1.017
West Bengal	1.000	1.039
Odisha	1.040	1.034
Maharashtra	0.966	1.09
Gujarat	0.968	1.068
Rajasthan	1.000	1.059
Madhya Pradesh	0.964	1.054
Mean	0.983	1.057

production efficiency. Milk prices crash have hit the domestic milk market forcing the number of small and marginal dairy farmers to move out of dairy business (Food Sovereignty Alliance, 2017). In 1999, quantitative restrictions placed on skimmed milk powder (SMP) were abolished to abide by WTO regulations, which led to spike in SMP imports causing domestic milk prices to crash. Another major price crash hit in 2015, when SMP exports started rising in the global market, and due to the high price SMP could not be sold resulting in huge domestic build-up of stocks. Emerging threats from transboundary diseases calls for greater financing for animal health, improved monitoring and quarantine system (Otte, Nugent and McLeond 2004).

Conclusions and implications

This study has attempted to estimate the TFP growth in India's livestock sector using a panel dataset of sixteen states from 1990-91 to 2015-16. At the national level, the TFP in India's livestock sector grew at an annual rate of 3.9%. However, there is considerable heterogeneity in TFP growth across states. Punjab, Haryana, Tamil Nadu, Andhra Pradesh, Odisha, Maharashtra and Rajasthan have performed much better on technological front. Jammu & Kashmir, Himachal Pradesh and Bihar rank at the bottom in terms of technological progress. At the national level, TFP growth has been driven by technical change, mainly due to the crossbreeding of non-descript cattle with exotic germplasm and expansion of preventive animal health care. Scale efficiency is estimated at 0.689% indicating the possibility of increasing output by about 30% by adjusting the herd size. There are wide differences in the efficiency levels across states, highlighting the existence of a scope to improve livestock production. These findings suggest increasing of investment in animal science research, linking research outputs to extension systems, improving breeding, feeding and animal health in the lagging states.

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Appendix

Table A1. Summary of changes in annual mean indices

Year	Efficiency change	Technical change	Pure efficiency change	Scale efficiency change	TFP change
1991-92	0.94	1.073	0.976	0.96	1.009
1992-93	0.933	1.086	1.04	0.9	1.013
1993-94	0.987	1.066	0.98	1.01	1.052
1994-95	0.979	1.047	1.002	0.98	1.025
1995-96	0.893	1.133	0.992	0.9	1.012
1996-97	0.942	1.101	0.989	0.95	1.037
1997-98	0.971	1.014	0.996	0.98	0.985
1998-99	1.135	0.9	1.034	1.1	1.022
1999-2000	0.803	1.297	0.949	0.85	1.041
2000-01	0.989	0.972	0.881	1.12	0.962
2001-02	1.036	0.993	0.925	1.12	1.029
2002-03	1.005	1.002	1.026	0.98	1.007
2003-04	1.135	0.831	1.018	1.12	0.944
2004-05	1.128	0.958	1.022	1.1	1.082
2005-06	0.818	1.289	0.967	0.85	1.054
2006-07	1.052	1.039	1.019	1.03	1.092
2007-08	0.932	1.152	0.999	0.93	1.074
2008-09	0.992	1.095	1.003	0.99	1.086
2009-10	1.013	1.093	0.987	1.03	1.107
2010-11	1.046	1.01	1.01	1.04	1.056
2011-12	0.85	1.134	1.033	0.82	0.965
2012-13	0.922	1.099	0.989	0.93	1.013
2013-14	1.04	1.079	0.974	1.07	1.122
2014-15	1.093	1.017	0.997	1.1	1.112
2015-16	1.037	1.064	1.014	1.02	1.104
Mean	0.983	1.057	0.992	0.99	1.039

Table A2 Estimates of Malmquist TFP indices by state

Year	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Haryana	1.115	1.022	1.06	1.005	0.998	1.029	1.034	1.042	1.089	1	1.003	0.988	1.024	0.941	1.051	1.122	1.27	1.072	1.219	1.058	0.931	1.161	1.069	1.225	0.952
Punjab	1.355	0.871	1.254	1.219	1.154	1.062	0.818	1.132	0.906	1.255	1.346	0.882	1	1.044	1.003	1.354	1.046	0.858	1.207	1.017	0.419	1.037	1.798	0.892	1.074
UP	1.044	0.952	0.977	1.027	0.984	1.024	1.061	1.026	1.004	0.936	1.071	0.958	1.03	1.032	1.027	0.993	1.055	1.099	1.121	1.05	1.121	1.019	1.154	1.141	1.103
HP	0.966	0.993	0.984	0.984	0.986	0.989	1.013	1.051	1.054	0.993	1.027	1.112	1.061	0.936	1.052	0.664	0.995	1.216	0.983	0.962	1.216	0.909	1.01	1.037	1.093
J&K	0.621	0.886	0.933	0.9	0.897	0.863	0.909	1.003	1.237	0.725	0.814	1.015	0.93	0.962	0.939	0.905	1.127	1.105	1.208	1.042	0.609	1.371	0.97	1.12	1.28
AP	1.069	1.081	1.183	1.138	0.819	1.139	0.94	0.826	1.631	1.101	1.262	1.22	0.958	1.195	0.964	0.858	1.041	1.058	1.17	1.045	0.749	0.982	1.607	1.137	1.167
Karnataka	0.978	1.06	1.068	1.014	1.05	1.043	1.075	0.961	0.977	1.006	1.01	0.948	0.782	1.048	1.038	0.948	1.215	1.255	0.946	1.11	1.19	1.071	0.956	1.348	1.049
Kerala	1.197	1.194	1.063	1.039	1.111	1.077	0.951	1.374	0.804	1.057	0.96	0.923	0.794	0.804	1.334	0.986	1.206	1.178	1.084	1.019	1.252	1.06	0.991	0.965	1.068
TN	1.23	1.161	0.918	1.075	0.907	1.031	0.941	2.411	0.378	1.009	1.091	1.022	1.027	1.219	1.101	1.262	1.137	1.158	1.258	1.294	1.082	1.077	1.162	1.196	1.059
Bihar	0.529	0.79	1.147	0.915	1.018	1.156	1.051	0.972	1.021	1.016	1.168	0.934	0.769	1.259	1.033	0.872	0.993	1.17	0.994	0.96	1.116	1.085	1.098	1.092	1.08
WB	1.01	1.025	1.072	1.031	1.191	1.125	0.967	0.598	1.589	0.729	0.975	1.358	0.888	1.182	1.112	0.598	1.439	1.135	1.127	1.005	1.097	1.03	1.099	1.102	1.085
Odisha	1.171	1.052	1.163	0.972	1.072	1.077	1.069	1.049	1.023	1.052	1.068	1.033	1.265	1.026	0.967	1.136	1.143	1.208	1.159	1.014	1.092	1.081	1.006	1.045	1.026
Maharastra	1.04	1.127	0.94	1.025	1.03	1.019	1.003	1.029	0.991	1.018	0.972	1.013	1.005	1.003	1.119	1.308	0.98	1.115	1	1.033	1.094	1.044	1.249	1.128	1.162
Gujarat	1	1.171	0.955	1.069	1.075	1.03	0.985	1.005	0.922	1.04	0.962	0.951	0.979	0.987	1.122	1.021	1.132	1.003	1.045	1.154	1.06	1.041	1.025	1.082	1.068
Rajasthan	1.098	0.932	1.182	0.972	1.047	1.016	0.939	1.148	1.034	0.857	0.858	0.9	0.964	1.156	1.351	6.339	0.665	0.892	1.242	1.019	0.382	1.032	1.132	1.22	1.175
MP	1.102	0.99	1.014	1.023	0.952	0.952	1.031	1.003	1.139	0.947	0.822	0.949	0.939	1.042	1.092	0.89	0.949	0.944	1.016	1.167	1.022	1.051	1.04	1.142	1.274

Table A3 Estimates of Efficiency by state

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Haryana	1	1	1	1	1	1	1	1	1	0.951	1.055	0.973	1.025	1	0.946	1.057	1	1	1	1	1	1	1	1	1
Punjab	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
UP	0.97	0.782	0.961	0.966	0.869	0.927	0.982	1.049	0.81	0.917	1.129	1.02	1.267	1.113	0.808	0.952	0.926	1.083	1.074	1.014	0.997	0.905	1.076	1.116	1.024
HP	0.918	0.781	0.956	0.931	0.865	0.89	0.945	1.061	0.824	0.946	1.015	1.136	1.277	1.013	0.778	0.589	0.846	1.145	0.955	0.991	0.844	0.967	0.972	1.167	1.024
J&K	1	1	1	1	0.902	0.782	0.841	1.027	0.996	0.715	0.861	1.085	1.15	1.088	0.703	0.806	0.972	0.846	1.061	1.013	0.515	1.111	0.939	1.135	1.218
AP	0.772	1.016	0.979	1.068	0.745	0.991	0.836	0.818	1.332	1.014	1.224	1.246	1.152	1.294	0.685	0.719	0.871	0.988	1.131	1.074	0.642	0.888	1.631	1.127	1.077
Karnataka	0.762	0.92	0.923	0.922	0.978	0.912	0.99	0.968	0.763	0.991	1.084	1.022	0.991	1.153	0.772	0.917	1.028	1.193	0.92	1.151	0.766	1.139	0.921	1.494	0.968
Kerala	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
TN	0.889	1.091	0.76	1.008	0.825	0.897	0.837	2.388	0.301	0.917	1.114	1.043	1.239	1.292	0.782	1.086	0.967	1.087	1.195	1.252	0.821	0.915	1.129	1.165	0.98
Bihar	0.746	0.654	1.189	0.84	0.957	1.02	1.265	1.042	0.764	1.035	1.265	0.938	0.934	1.485	0.835	1.044	0.833	1.153	0.926	0.978	0.946	0.997	1.022	1.031	0.97
WB	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Odisha	1.187	1.004	1.096	0.941	0.695	1.019	1.085	2.62	0.428	2.465	1.05	0.646	0.917	1.34	0.672	1.874	1	1	1	1	1.011	1	0.989	1	1
Maharastra	0.87	0.952	0.871	0.974	0.908	0.946	0.972	1.039	0.772	0.955	1.008	1.046	1.05	1.316	0.783	1.08	0.82	1.001	0.921	1.004	0.912	1.02	0.905	1.085	1.093
Gujarat	0.847	0.993	0.875	1.027	0.94	0.923	0.922	1.015	0.733	1.082	0.942	1.012	1.177	0.798	1.237	0.959	0.968	0.955	1.008	1.167	0.891	0.91	0.981	1.016	0.982
Rajasthan	1.145	0.922	1.265	0.973	0.907	0.938	0.944	1.204	0.869	0.865	0.839	0.946	1.236	0.809	1.419	3.876	0.905	0.66	1.076	0.945	0.326	0.86	1.106	1.173	1.105
MP	1.064	0.917	1.03	0.977	0.825	0.863	0.995	1.017	0.909	0.998	0.806	1.016	1.18	0.814	1.163	0.836	0.816	0.897	0.981	1.196	0.805	0.906	0.997	1.079	1.198

Table A4 Estimates of technical change by state

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Haryana	1.115	1.022	1.06	1.005	0.998	1.029	1.034	1.042	1.089	1.051	0.951	1.016	0.999	0.941	1.111	1.061	1.27	1.072	1.219	1.058	0.931	1.161	1.069	1.225	0.952
Punjab	1.355	0.871	1.254	1.219	1.154	1.062	0.818	1.132	0.906	1.255	1.346	0.882	1	1.044	1.003	1.354	1.046	0.858	1.207	1.017	0.419	1.037	1.798	0.892	1.074
UP	1.075	1.217	1.017	1.064	1.132	1.105	1.08	0.978	1.24	1.021	0.949	0.94	0.814	0.927	1.272	1.043	1.139	1.015	1.044	1.035	1.125	1.126	1.072	1.023	1.077
HP	1.053	1.272	1.029	1.057	1.14	1.111	1.072	0.99	1.278	1.05	1.012	0.979	0.831	0.923	1.351	1.129	1.176	1.062	1.03	0.971	1.44	0.94	1.038	0.888	1.067
J&K	0.621	0.886	0.933	0.9	0.995	1.104	1.081	0.976	1.242	1.014	0.946	0.936	0.809	0.884	1.336	1.124	1.159	1.306	1.139	1.028	1.183	1.234	1.033	0.987	1.051
AP	1.384	1.064	1.208	1.066	1.099	1.149	1.125	1.009	1.224	1.086	1.031	0.979	0.831	0.923	1.409	1.194	1.195	1.071	1.034	0.973	1.166	1.106	0.985	1.009	1.083
Karnataka	1.283	1.153	1.158	1.099	1.073	1.143	1.085	0.993	1.279	1.015	0.932	0.928	0.789	0.909	1.344	1.035	1.183	1.052	1.028	0.965	1.553	0.941	1.038	0.902	1.084
Kerala	1.197	1.194	1.063	1.039	1.111	1.077	0.951	1.374	0.804	1.057	0.96	0.923	0.794	0.804	1.334	0.986	1.206	1.178	1.084	1.019	1.252	1.06	0.991	0.965	1.068
TN	1.384	1.064	1.208	1.066	1.099	1.149	1.125	1.009	1.255	1.1	0.98	0.979	0.829	0.943	1.409	1.162	1.176	1.065	1.053	1.034	1.319	1.178	1.03	1.027	1.08
Bihar	0.71	1.208	0.965	1.089	1.065	1.134	0.83	0.933	1.336	0.981	0.923	0.996	0.823	0.848	1.238	0.835	1.192	1.015	1.074	0.981	1.18	1.088	1.074	1.059	1.114
WB	1.01	1.025	1.072	1.031	1.191	1.125	0.967	0.598	1.589	0.729	0.975	1.358	0.888	1.182	1.112	0.598	1.439	1.135	1.127	1.005	1.097	1.03	1.099	1.102	1.085
Odisha	0.986	1.048	1.061	1.033	1.542	1.057	0.985	0.4	2.389	0.427	1.017	1.599	1.379	0.766	1.439	0.606	1.143	1.208	1.159	1.014	1.081	1.081	1.016	1.045	1.026
Maharastra	1.196	1.183	1.079	1.052	1.135	1.077	1.032	0.991	1.283	1.066	0.964	0.969	0.957	0.762	1.43	1.212	1.195	1.113	1.086	1.029	1.2	1.024	1.38	1.04	1.064
Gujarat	1.181	1.18	1.092	1.04	1.143	1.116	1.068	0.99	1.259	0.962	1.022	0.939	0.832	1.236	0.907	1.065	1.17	1.051	1.037	0.989	1.19	1.143	1.045	1.065	1.088
Rajasthan	0.958	1.011	0.934	0.999	1.155	1.084	0.994	0.954	1.189	0.99	1.023	0.951	0.78	1.429	0.952	1.635	0.734	1.353	1.154	1.078	1.173	1.2	1.024	1.04	1.064
MP	1.036	1.08	0.985	1.048	1.154	1.103	1.037	0.986	1.253	0.949	1.02	0.935	0.796	1.28	0.939	1.065	1.163	1.053	1.035	0.976	1.269	1.16	1.043	1.059	1.064