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Economic impact of public research investment on livestock productivity: evidence from India

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Abstract Limited literature and outdated estimates on economic impact of livestock research investment in Indian context motivated us to undertake this study. It attempts to fill the gap by utilizing a unique panel dataset of 15 states from 1991-92 to 2017-18. Using fixed effects panel regression approach, we find that investment on livestock research has significant positive impact on livestock productivity. Regionally, the impact was higher in north followed by south, east and west zones. Overall, a high marginal internal rate of return to research investment (40.9%) indicates substantial economic gains. Findings of the study reiterates that research investment is crucial determinant of productivity growth, thus recommends higher allocation of resources to livestock research.

Keywords Livestock, Productivity, Research, Impact, Economic Returns, Fixed effects

JEL codes Q1, Q10, Q12

Introduction

In India, livestock is a key contributor to agricultural sector. Its share in the gross value of agricultural output is estimated at 27%. It performs both food and non-food functions. However, in recent years, the non-food functions such as draught power, dung has declined with the advent of mechanization and chemical fertilizers. As urbanisation and economic expansion progress, the food function is likely to gain more prominence. Demand for animal origin food products is expected to rise further in the future which will put additional strain on finite land, water, and energy resources (Delgado et al. 1999). Despite being home to largest livestock population, milk productivity in India is one of the lowest in the world. Global climate change, limited natural resources and rising incidences of zoonotic diseases, threatens the sustainability of existing livestock production system which is largely driven by cattle population.

ICAR through its cooperation with various international agricultural research organisations such as International Maize and Wheat Improvement Centre (CIMMYT), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), International Rice Research Institute (IRRI) has been instrumental in boosting farm productivity and food security (Rosegrant and Evenson 1992; Fan et al. 1999; Joshi et al. 2005; Chand et al. 2011). Much of the success of Green Revolution was due to large scale public investment undertaken in crop genetic improvement. The research-led productivity growth in staple crops transformed many food deficits nations into food surplus nations (Rosegrant and Hazell 2000; Fan 2007). The existing evidence suggests that agricultural research investment has poverty eliminating effects with high economic rate of returns (Evenson et al. 1999; Byerlee 2000; Fan and Thorat 2000; Chand et al. 2012; Rada and Schimmelpfennig 2018). However, technological bias brought about by Green Revolution, not only increased the social disparity but also led to massive ecological degradation (Pingali and Rosegrant 1994; Freebairn 1995). Although persistence of poverty, hunger and environmental degradation has raised sustainability concerns surrounding these innovations. Noticeably, these studies have been largely concentrated on crop research. Most of the empirical work on the adoption and diffusion of high-yielding technologies in developing countries focus on the crop sector, while very little is known regarding innovations in livestock sector (Abdulai and Huffman 2005). Globally some of the earliest studies (Peterson 1966; Widmer et al. 1987; Fox et al. 1992) estimated that economic gains of investing in poultry, beef, swine and dairy cattle research in the US and Canada are substantial. In India, studies showed that adoption of cross breeds leads to higher yield (25-40% output growth) as well as income gain (Kumar et al. 1977; Gaddi and Kunnal 1996; Kumar and Gupta 2000; Kumar et al. 2003; Bhowmik et al. 2006; Chandel et al. 2007). Most often livestock research is known to generate more puzzling outcomes than crop technologies (Haan 1995) due to biological nature and long gestation period. Numerous livestock technologies related to feed, breed, health care and housing have been developed and commercialised by ICAR Research Institutes and State Agricultural and Veterinary Universities. However, literature pertaining to their adoption and impact is almost non-existing. Most of the economic estimates regarding impact of livestock technologies (mainly crossbreed) in Indian context are outdated.

Therefore, present study is a modest attempt in this regard to provide more recent evidence and assess the economic gains from public investments in livestock research and education in India. Firstly, we build a fixed effects panel regression model to identify the major determinants of livestock productivity (TFP) and estimate their impact. Thereafter, Marginal Internal Rate of Return (MIRR) is calculated to estimate the economic returns to livestock research investment.

Data and Methodology

In order to select the sample for the study, we identify all the institutions working under the animal science division of ICAR. A total of 45 institutes were identified of which 19 were central level research institutions under direct administrative control of ICAR, 15 independent state veterinary universities and 11 veterinary colleges which are part of existing state agricultural universities (Fig 1). Based on the location of institutions, fifteen states were identified which were further incorporated into four zones (North, East, West and South) to carry out regional analysis. A unique panel data set of fifteen states namely, Andhra Pradesh, Bihar, Gujarat, Himachal Pradesh, Haryana, Karnataka, Kerala, Madhya Pradesh (MP), Maharashtra, Odisha, Punjab, Rajasthan, Tamil Nadu, Uttar Pradesh (UP) and West Bengal, from 1991-92 to 2017-18 was developed after collecting data on several variables required in the study (Table 1). Bihar, MP and UP include the pre-incorporated states of Jharkhand, Chhattisgarh and Uttarakhand respectively. Since there was only one state i.e., MP in central zone, it was incorporated with the West zone for the analysis purpose.

Table 1 Selection of states and zones

Zone	States
North Zone	Punjab, Haryana, Uttar Pradesh and Himachal Pradesh
East Zone	Assam, Odisha, Bihar and West-Bengal
West Zone	Maharashtra, Rajasthan, Gujarat
Central Zone	Madhya Pradesh
South Zone	Andhra Pradesh, Karnataka & Tamil Nadu

Note Bihar, UP &MP are pre-bifurcation states

In order to meet the objective of the study following variables were formulated:

i. **TFP index:** This study uses non-parametric Malmquist index (DEA approach) to measure TFP. 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 data on the overall value of livestock output is disaggregated into seven groups: milk, meat, egg, wool and hair, silk, dung, increment in animal stock, silk worm cocoon, and honey, according to National Account Statistics. Except silkworm cocoon and honey, data for all six product groups were collected in current prices and then converted into constant prices using wholesale price index with 2011-12 base prices. This aggregate measure was used as value of livestock output.

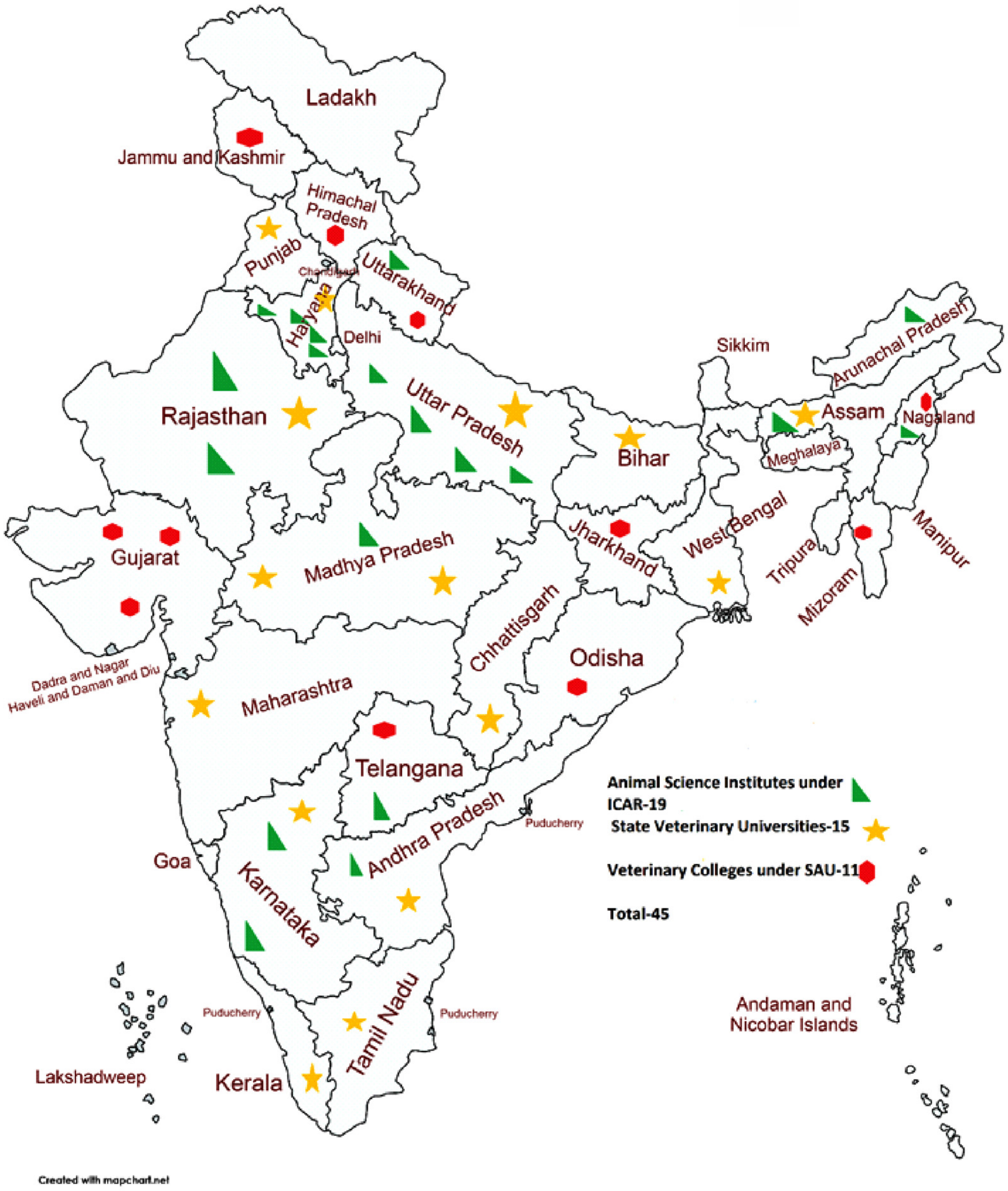

Figure 1 Distribution of Animal Science Research Institutions in India

Three major input groups used are: feed, labour and animal stock. State-wise green fodder production was estimated using the area under green fodder. Besides fodder area, the land under permanent pastures, cultivable wasteland, grazing land, land under miscellaneous uses were clubbed together to estimate fodder availability from those lands. State-wise data on the annual value of straw and stalks were collected and converted into constant 2011-12 base prices to be taken as a measure of value of dry fodder production. For detailed methodology and estimates of Malmquist TFP indices refer (Kathayat et al. 2022).

Labour: To estimate the labour population engaged 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 2004; Chand and Sirohi 2015). Interpolation was done to estimate the labour population for inter-census periods.

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

ii. **Livestock research and education (LRE) stock:** To develop LRE stock variable, annual budget data of selected state as well as national level institutions engaged in livestock research and education was collected. Since direct research expenditure variable cannot be used for assessing its impact, creation of a research stock variable as a suitable indicator is widely prevalent in literature (Alston and Pardey 2001). Basically, LRE stock variable determines the pathway through which knowledge or technology generated as a result of persistent research activity leads to productivity growth. It takes into account the temporal aspect of the attribution problem as well. Based on the conceptual framework provided by (Alston et al. 1995(a)) knowledge stock is assumed to be a result of recurring past and current research investments by taking lagged research investments. Modelling these effects involve use of finite distributed lag structure. Polynomial distributed lag (PDL) was one the earliest lag structure to be used. Later on, some offshoots of PDL arose, such as trapezoid (Huffman and Evenson 1993) geometric and the gamma (Alston et al. 2010) have been more common. Choice of lag length and weights were mostly made arbitrarily in past studies ranging from free form to using certain criteria such as R square for selection of lag length (Fan et al. 2000). In order to account for that lag, we created LRE stock following the trapezoid lag scheme given by (Evenson 2001) by testing the alternate lag length of 8, 10,13 and 14 years (Table 1). Due to availability of data for the limited time period, we cannot exceed lag length beyond 14 years in the present study. On the basis of sign and significance level and lowest Akaike information criterion (AIC) and Bayesian information criterion (BIC) value, LRE stock using 14 years lag (equation 4) was found to be the best fit (Table 2). Lag Structure (2, 4, 2, 6) assuming 2-year lag for adoption of technology, 4 years of increasing impact, 2 years of peak impact and 6 years of declining impact was used to create research stock variable (Fig 2). After six years of declining impact, it was assumed that knowledge stock becomes obsolete and requires replacement by new technology/knowledge.

$$LRE\ stock_{it} = 0 * LRE_{1994i} + 0 * LRE_{1995i} + 0.02 * LRE_{1996i} + 0.05 * LRE_{1997i} + 0.1 * LRE_{1998i} + 0.15 * LRE_{1999i} + 0.2 * LRE_{2000i} + 0.2 * LRE_{2001i} + 0.1 * LRE_{2002i} + 0.08 * LRE_{2003i} + 0.06 * LRE_{2004i} + 0.02 * LRE_{2005i} + 0.01 * LRE_{2006i} + 0.01 * LRE_{2007i}$$

iii. **Veterinary infrastructure (VH):** Secondary data on state-wise number of veterinary hospitals, polyclinics, dispensaries and veterinary aid-centre were compiled from various issues of Basic Animal Husbandry and Fisheries statistics for the selected states. Wider coverage of veterinary infrastructure enables greater access to scientific health care reducing the incidences of various diseases such as zoonotic diseases, epizoonosis and endoparasites etc. hence minimizing losses.

Table 2 Selection of lag structure for LRE stock variable

Dependent variable	ln TFP			
Regressors (→)	Equation 1	Equation 2	Equation 3	Equation 4
LRE stock (8)	0.11			
LRE stock (10)		0.080		
LRE stock (13)			0.128**	
LRE stock (14)				0.198**
Constant	-0.565	-0.396	-0.801	-1.058**
State fixed effects	Yes	Yes	Yes	Yes
AIC	90.83	96.93	39.14	-5.811
BIC	94.37	100.39	42.33	-2.705

Note *p< 0.10,** p<0.05, ***p<0.01

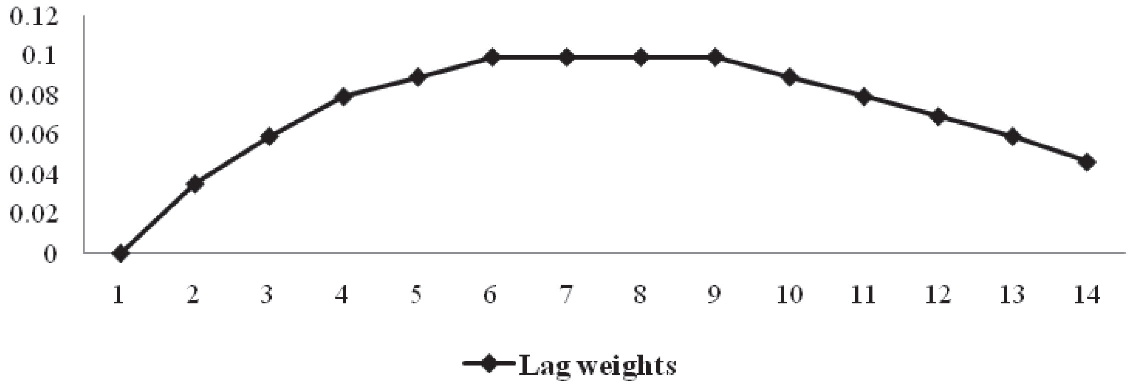

Figure 2 Trapezoidal lag scheme for developing livestock research and education (LRE) stock

iv. **Artificial insemination (AI):** Secondary data on number of artificial inseminations performed were taken from Basic Animal Husbandry and Fisheries statistics. Artificial Insemination is widely used breed improvement technique to improve milk yield of native breed by inseminating with high pedigree/exotic bull semen. Wider penetration of AI indicates higher adoption of high yielding breeds.

v. **Annual mean rainfall (Rain):** It was used as a measure of weather effect which might influence productivity positively as well as negatively indirectly through its effect on forage production and spread of diseases. State-wise annual mean rainfall data were compiled from RBI Handbook of Statistics on Indian States.

vi. **Road density (Rd):** Road density was measured as the total road length in the state normalized by state area (km per 1000 sq km area). Roads facilitates input delivery and provide access to markets for products thereby contributing to productivity. This data was collected from Basic Road Statistics of India.

vii. **Expenditure on education as ratio to aggregate expenditure (edu):** It was used as a proxy variable for literacy to depict the human resource development status of the region. Improved education helps people to move out of farming and find non-farm employment opportunities. It might also induce people to become more entrepreneurial and take up small business enterprises. The data was also compiled from RBI Handbook of Statistics on Indian States.

Analytical tools

Fixed Effects Panel regression approach was used to capture the relationship between predictor (Xs) variables and outcome variable ($\ln TFP_{it}$) within an entity (state in this case). When using Fixed Effects, we assume that each state has some time-invariant individual characteristics that might influence predictor variable. Therefore, we control for those state individual fixed effects that might bias the results. Following econometric equations were established for the purpose of this study:

$$lnTFP_{it} = \beta_0 + \beta_{lre}\, lnLRE_{it} + state\ FE + error \qquad 1(a)$$

$$lnTFP_{it} = \beta_0 + \beta_{lre}\, lnLRE_{it} + \beta_{rain} Rain_{it} + \beta_{road} lnRoad_{it} + \beta_{ai} lnAI_{it} + \beta_{vh} lnVH_{it} + \beta_{edu} edu_{it} + state\ FE + error \qquad 1(b)$$

$$lnTFP_{it} = \beta_0 + \beta_{lre}\, lnLRE_{it} + \beta_{r-1}\,(Zone * LRE_{it}) + state\ FE + error \qquad 2(a)$$

$$lnTFPit = \beta_0 + \beta_{lre}\, lnLRE_{it} + \beta_{rain} Rain_{it} + \beta_{road} lnRoad_{it} + \beta_{ai} lnAI_{it} + \beta_{vh} lnVH_{it} + \beta_{edu} edu_{it} + \beta_{r-1}\,(region * LRE_{it})\ edu_{it} + error \qquad 2(b)$$

Equation 1(a) and 1(b) assesses the individual impact of livestock research and overall impact of different variables on TFP while controlling for state individual fixed effects respectively.

Equation 2(a) and (b) makes further distinction by accounting for zone wise separate impact by region dummy variable (Rr-1) with r indexes indicating four zones (North, East, West and South).

Marginal Internal Rate of Return (MIRR) was estimated using parameters (regression coefficients) obtained from Fixed Effects equation. MIRR is the discounted rate at which the present value of benefit stream of expected value of marginal product (EVMP) of research is equated to one. Research-induced value of production (V) could be estimated when percentage

Table 3 Model diagnostic tests

Test		Null hypothesis	Test statistics	Conclusion
Model Selection	BPG LM test	No panel effect (Variances across entities are zero)	chibar2(01) = 0.00 Prob > chibar2 =1.00	Fail to Reject Null Evidence of panel effect
	Hausman test	Preferred model is random effects	chi2(1) = 6.79 Prob>chi2 = 0.009	Reject Null Fixed effects is the preferred model
Group wise Heteroskedasticity in Fixed Effects Regression	Modified Wald test	Homoskedasticity (constant variance)	chi2 (15)=11299.82 Prob>chi2 = 0.00	Reject Null Heteroskedasticity is present
Correlation among X variables		Below 0.7 for all variables		Low

share of research in TFP is multiplied with average value of production.

Value of output per unit investment (V)–Research-induced value of production was obtained by multiplication of technical coefficient of research stock with growth rate of research stock to determine the contribution of research to TFP. This value is further multiplied with average value of production to know research induced value of production.

Expected value of marginal product of investment (EVMP) - It was derived using the following formula:

$EVMP = \beta_{lre} * (V/R)$

β_{lre}= Elasticity of research stock; V= Research induced value of production; R=Average value of research stock

Estimated elasticity of TFP with respect to research stock (β_{lre}):

$\beta_{lre} = \partial\log(TFP) / \partial\log(LREstock)$

In order to estimate the benefit stream, it was assumed that total benefits from the research investment are spread over a period of 20 years at varying rates. Initially, a minimum gestation lag of six years was assumed before investment starts generating benefits. After initial six years lag period, benefits start flowing in at an increasing rate for the initial four years followed by constant rate for the next six years and eventually starts declining at a decreasing rate for latter four years. Below equations provides the assumption regarding the structure at which returns from an investment starts to generate.

Benefits rising at an increasing rate:

$0.2 * (EVMP)_{t+6} + 0.4 * (EVMP)_{t+7} + 0.6 * (EVMP)_{t+8} + 0.8 *(EVMP)_{t+9}$

Benefits rising at a constant rate:

$1 * (EVMP)_{t+10} + 1 * (EVMP)_{t+11} + 1 * (EVMP)_{t+12} + 1 * (EVMP)_{t+13} + 1 * (EVMP)_{t+14} + 1 * (EVMP)_{t+15}$

Benefits declining at a decreasing rate:

$0.8 * (EVMP)_{t+16} + 0.6 * (EVMP)_{t+17} +0.4 * (EVMP)_{t+18} +0.2 * (EVMP)_{t+19}$

Overall benefit stream was obtained by summation of all the above benefits streams

$$B_k = \sum_{k=1}^{t=20} W_{t-i+k}\,[b_r(V_{t-i-k}/M_{t-i})] = \sum_{k=1}^{t=20} EVMP_k$$

W_{t-i+k} = weights given to investment made in time t–i–k period

B_k = Benefit stream

This stream was discounted at various discount rates (d) until the discount rate appears at which present value of the benefit stream becomes equal to one. This discount rate is considered as the marginal internal rate of return (MIRR) to investment.

$$PV_{t-i} = \frac{\sum_{k=0}^{i} B_k}{(1+d)^k}$$

Table 4 Fixed effects panel regression without region interaction term

Dependent variable	lnTFP	
Regressors	Equation 1(a)	Equation 1(b)
LRE stock(log)	0.198**	0.140
	(0.084)	(0.108)
Road density(log)		0.019
		(0.035)
AI(log)		0.040
		(0.058)
Veterinaryinfra(log)		0.129
		(0.110)
Edushare(%)		-0.029**
		(0.012)
Annual mean rainfall(log)		-0.133
		(0.073)
Constant	-1.058**	-0.867
	(0.468)	(1.544)
Rho	0.190	0.409
State fixed effects	Yes	Yes
AIC	-5.811	-5.711
BIC	-2.705	12.901
No. of groups	165	165
Observations	15	15

Note Values in parentheses are robust standard errors *p<0.10,** p<0.05, ***p<0.01

Table 5 Fixed effects panel regression with region interaction term

Dependent variable	lnTFP	
Regressors	Equation 2(a)	Equation 2(b)
North *LRE	0.645***	0.516*
	(0.149)	(0.259)
South*LRE	-0.457**	-0.312
	(0.204)	(0.350)
East*LRE	-0.535**	-0.672***
	(0.165)	(0.223)
West*LRE	-0.567**	-0.513*
	(0.156)	(0.305)
Road density(log)		0.030
		(0.072)
AI(log)		0.051
		(0.077)
Vet. Infra(log)		0.159
		(0.170)
Edushare(%)		-0.032**
		(0.014)
Annual Mean Rainfall(log)		-0.119
		(0.077)
Constant	-1.433***	-1.49
	(0.333)	(1.074)
Rho	0.969	0.973
State Fixed Effects	YES	YES
AIC	-3.096	-4.067
BIC	9.327	23.886
No. of groups	165	165
Observations	15	15

Note Values in parentheses are robust standard errors *p<0.10,** p<0.05, ***p<0.01

Results and discussion

Impact of livestock research and education on TFP

To assess the economic impact of livestock research and education on TFP, using fixed effect panel regression approach four econometric equations were formulated. In these equations, β_{lre} represents the research elasticity which indicates the research stock's influence on TFP *ceteris paribus*. Similarly, other coefficients indicate impact of the respective explanatory variable on TFP.

As stated earlier, equation 1(a) in Table 4 assessed the overall impact of livestock research stock on TFP while controlling for state individual fixed effects. Findings of equation 1(a) highlights the public research investment has significant positive impact on livestock productivity. We find that with one unit rise in LRE stock, TFP is likely to increase by 19.8 per cent *ceteris paribus* (Table 4). Equation 1(b) incorporates other explanatory variables and suggests that literacy variable (Edushare) and rainfall had significant negative impact on TFP. Equation 2(a) in Table 5 takes into account region dummy variable (R_{r-1}) with r indexes indicating four zones (North, East, West and South) to demonstrate the separate zone wise impact of livestock research on the TFP of the corresponding region. North zone acts as reference category for other region dummies. It was seen that across regions, livestock research had the largest impact on TFP in North and lowest in West zone. As per our estimates, with one unit rise in LRE stock, TFP increases by 64 per cent in North, 19 per cent in South, 10 per cent in East and about 7 per cent in West zone (Table 5). Due to widespread availability of favourable infrastructure and proximity to national research stations, research spill-over and uptake is likely to be higher in North zone compared to other zones (Rada and Schimmelpfennig 2018).

The findings of the equation 2(b) were consistent with those of equation 1(b) with respect to estimated negative impact of share of education expenditure (indicator for literacy) and rainfall on livestock TFP. With one per cent rise in literacy variable (Edushare), TFP was observed to be declining by approximately 3 per cent. The estimated negative impact of education here may not appropriately capture the education level of farming population engaged in livestock activities and therefore leading to counter-intuitive results. Higher spending on education leads to better human resource development (HRD), which in turns opens up new opportunities resulting into transfer of better-educated labour force out of agriculture towards secondary and tertiary sectors. This could be the plausible reasoning behind the observed negative impact of education variable on TFP and similar findings have been obtained by (Rosegrant and Evenson 1992).

Although road density, artificial insemination and veterinary infrastructure showed positive association with TFP but their effect was statistically insignificant. All these variables collectively demonstrate the impact of improved infrastructure on productivity caused by reduction in productivity losses due to poor health and diseases. Our findings highlight that livestock research investment has most significant impact on productivity among the selected variables and the magnitude of impact was found to be highest for north zone followed by south, east and west zone. This study provides strong evidence of productivity enhancing effects of research activity and therefore argues in favour of greater allocation to livestock research.

Economic returns to research investment in livestock sector

The estimated coefficients of the research stock variable were used to compute expected value of marginal product (EVMP) of the research stock and marginal internal rate of return (MIRR). Overall EVMP for all zones was estimated to be Rs. 95.75, indicating the potential of higher economic gain from livestock research investment. It is evident from Table 6 that highest EVMP was obtained for North zone (Rs.313.18) followed by East zone (Rs.64.64), West (Rs.56.95) and South (Rs.52.61). These findings suggest that every additional rupee invested in livestock research is likely to generate greater benefits in all regions of the country however benefits are greatest for north zone. Based on our assumption outlined in methodology section, an additional rupee invested in research in time t leads to generation of an income stream after an initial gestation of six years, after that income starts rising at an increasing rate for the first four years from Rs. 19.51 from t+6 to Rs. 76.60 in t+9, thereafter it generates benefits at a constant rate of Rs. 95.75 from t+10 to t+15. Later on, benefits start increasing at a declining rate from t+16 onwards up to t+19.

Table 6 Zone wise expected value of marginal product and marginal internal rate of return

Region	Expected value of marginal product (in rupees‘)	Marginal internal rate of return (in %)
North	313.18	49.5
East	64.64	38.2
West	56.95	37.3
South	52.61	36.7
Overall	95.75	40.9

Zone-wise estimates reveal that the North zone had the highest MIRR (49.5%). The overall marginal internal rate of return (MIRR) was found to be 40.9 per cent. The presence of large number of animal science research institutes as well as strong state level funding, allow for higher information spill-over and technology adoption in this North region, which could be the plausible reason behind higher rate of returns. Despite being an agriculturally underdeveloped region, the East zone had the second highest MIRR (38.2%) indicating high potential for livestock sector in the region. Livestock constitute a major share of agricultural income in the East zone which has comparatively higher rates of poverty and malnutrition prevalence than the rest of the country. Focussing on location specific livestock research and its wider penetration has the potential to improve TFP growth leading to poverty eliminating effects in this region.

Livestock provides a suitable alternative for economic development of the region. The Western zone's MIRR was 37.3 percent. In this zone, Gujarat was the poster child for the success of the dairy cooperative movement–known for bringing prosperity to dairy households by improving marketing linkage. However, this was not the case for other states in the Western zone, wherein livestock research seems to be receiving low sectoral priority which is reflected in terms of its lower MIRR. Among all zones, South zone yielded lowest MIRR (36.7%) quite surprisingly. Lower adoption of livestock technologies such as cross breeds or lack of any region-specific breakthrough could be the possible reasons behind lower MIRR in South region. However, it may be concluded that, although investment in livestock research yields lower economic gains in terms of magnitude in the South zone than other zones, the returns were still significant enough to justify additional allocation.

There are many ways in which the research output from livestock maybe further augmented. There is need to strengthen the scientific staff and research capacity of most state level veterinary colleges and universities for development of location specific technologies and innovations. Also, most of the livestock innovations and technologies remain confined to the laboratory due to poor linkage between technology generator and disseminator. Hence, livestock extension mechanism might be strengthened in similar lines of crop sector. Findings of the study argue in favour of greater research allocation towards livestock research and timely impact evaluation of the ongoing research projects to assess their suitability and viability. For greater adoption of technical breakthroughs, there needs to be more collaboration amongst various stakeholders involved in the research to technology generation and dissemination process. Also, there is need to conduct more impact evaluation studies of individual livestock technologies so as to identify the factors hindering wider adoptability at farmer's level.

Conclusion

Livestock is a crucial sub-sector of agricultural economy in India with consistently rising share in agricultural GVA. Although success of crop research is well documented but empirical evidence in support of livestock research investment is almost non-existent. To fill the prevailing research gap, present study utilising a unique panel dataset of 15 major Indian states covering the period from 1991-92 to 2017-18 was undertaken. Several variables influencing livestock productivity such as research expenditure, veterinary infrastructure, artificial insemination, road density, weather and education variables were used to set up a fixed effects panel regression model and estimate economic returns. Findings suggests that investment in livestock research and education has overall significant positive impact on TFP, with per unit rise in research stock, TFP rises by almost 20 per cent. Notably the magnitude of research impact varied considerably across zones; North zone (64%) experienced highest impact on productivity, followed by South (19%), East (10%) and West (7%). Overall MIRR to livestock research investment were high (40.9%) indicating substantial economic gains of livestock research investment. With respect to return on research investment, North zone incurred greatest economic benefit with an estimated MIRR of 49.5 per cent followed by East (38.2 %), West (37.3%) and South (36.7%). Our estimates of economic returns are sufficiently high and stable thus establishing that research activity has strong influence on productivity improvement. Our findings reiterate the support for additional allocation to livestock research especially in the economically backward regions such as East zone.

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Appendix

A1. Summary statistics of the variables

Variable		Mean	Standard deviation	Observations
Total factor productivity index	Overall		0.39	N=432
	Between	1.06	0.08	n =16
	Within		0.38	T= 27
Livestock research and education (LRE) stock	Overall		161.11	N=165
	Between	301.25	152.39	n =15
	Within		64.41	T= 11
Annual mean rainfall	Overall		648.53	N=432
	Between	1172.34	632.44	n =16
	Within		211.52	T= 27
Road density	Overall		1190.98	N=432
	Between	1336.08	923.33	n =16
	Within		785.70	T= 27
Number of artificial inseminations performed	Overall		2003.16	N=432
	Between	2219	1220.58	n =16
	Within		1616.38	T= 27
Veterinary infrastructure	Overall		1505.88	N=432
	Between	3248	1385.19	n =16
	Within		681.67	T= 27
Share of education in aggregate expenditure (%)	Overall		2.73	N=288
	Between	14.82	2.14	n =16
	Within		1.76	T= 18