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Total Factor Productivity and Returns to Public Investment on Agricultural Research in India[§]

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Abstract

This study has estimated the total factor productivity (TFP) and its share in output growth, and returns to public investments on research in agriculture in India. The contribution of agricultural research in reducing real cost of production and attainment of food self-sufficiency has also been estimated for the country. The estimates of TFP have shown considerable variations across crops in different states and at all-India level during the period 1975-2005. These wide variations in TFP growth indicate that technological gains have not been experienced in a number of crops in many states. The TFP growth has helped in reducing the real cost of production in the range of 1.0–2.3 per cent annually in the case of cereals. This has helped in keeping the prices of cereals low for consumers and providing benefits to producers through a decline in the real cost of production. Returns to investment on agricultural research have been found to be a highly paying proposition. The study has suggested that further investments on research will generate significant returns. At the sector level (including crop and livestock), the TFP growth has contributed 15 per cent to output growth during 1990-91 to 2006-07. The returns to investment on agricultural research have been estimated at 42 per cent. Study has found that about one-fourth growth in the output of wheat and cotton, one-fifth in case of pearl millet, and around one-eighth in paddy and maize each have been achieved due to investments on agricultural research. In the year 2005-06, contribution of research in crop output has been estimated to be 10.4 Mt for wheat and 6.3 Mt for rice. In monetary terms, the contribution of research in the value of the nine selected crops has been computed as ₹ 1552 crore. The study has suggested a higher allocation of resources for development of agriculture in the country and attainment of national food and nutritional security.

Key words: Total factor productivity, research investment, food self-sufficiency, internal rate of return, resource allocation, agricultural research

JEL Classification: O47, Q16, Q12, Q18, D92

Introduction

India has made significant progress in the production of both food and non-food crops during the past four decades (1971-2011). During this period, the production of rice and foodgrains has more than doubled, of wheat, oilseeds and sugarcane has more than tripled, and of cotton has risen by 7-fold. This increase in production was driven by factors like suitable public policies, efforts in research and extension (R&E), use of modern farm inputs, public investment in infrastructure, etc. The increase in food production has ably addressed the challenge of food security in India. The increased foodgrain production has changed the status of country from a net importer

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to a net exporter for the past many years (Chand *et al.*, 2011).

The growth in production and productivity, however, has not been uniform across crops, regions and time periods. It is widely believed that rice and wheat and areas endowed with irrigation facilities have been the main beneficiaries of green revolution technologies, featuring improved seeds, higher use of chemical fertilizers and pesticides, and expanded irrigation, etc. However, a rigorous analysis of total factor productivity growth achieved through various means is lacking. Similarly, there is a serious concern about the recent trends in crop productivity which is echoed in the debates on technology and policy fatigue (Planning Commission, 2010; Narayanamoorthy, 2007). It is felt that the potential of green revolution technologies has reached its limits and it is not able to sustain the future growth in Indian agriculture. The debate is stretched to question the efficacy and contribution of research to the agricultural growth process. Again, a sound empirical analysis of the sources of growth and contribution of factors like research, education, extension, infrastructure, etc. in raising the crop productivity in recent years is missing. This paper makes an attempt to address these issues focusing on the following queries:

- What are the trends in TFP growth of various crops for different states and at all-India level during the period 1975-2005?
- How much are the returns to investment on research in agriculture? and
- What is the role of public sector agricultural research in output growth and how much is its contribution in attainment of food self-sufficiency?

The study has estimated the total factor productivity (TFP) for crops and states at the aggregate and disaggregate levels to assess the growth in productivity and to quantify the sources of TFP. The TFP measures growth of net output per unit of total factor input and quite a few studies on agricultural productivity have been undertaken in India during the past four decades or so, using TFP approach. They focus on estimating the effect of technological change on agriculture as a whole or total crop sector (Evenson and Jha, 1973; Rosegrant and Evenson, 1992). Due to non-availability of input allocation data at individual crop level, this may over- or under-estimate the TFP for the crop sector to the extent that rates of technological change differ across crops. Some studies (Sidhu and Byerlee, 1992; Kumar and Mruthyunjaya, 1992; Kumar and Rosegrant 1994; and Kumar, 2001) that have sought to estimate the TFP for individual crops, mainly rice and wheat, have not gone beyond mid-1990s.

Data and Methodology

Farm-level data on yield, use of inputs and their prices for major crops grown in different states during the period 1970-71 to 2005-06 were taken from the "Comprehensive Scheme for the Study of Cost of Cultivation of Principal Crops", Directorate of Economics and Statistics (DES), Ministry of Agriculture, Government of India. Based on the farm-level data, state-level data on cost of cultivation and yield that appeared in the Reports of the Commission for Agricultural Costs and Prices (CACP), published by the Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, were used to estimate crop-wise TFP. The missing year data on inputs and their prices were computed using interpolations in trends of the available data. The time-series data on infrastructural variables (road density, rail density, electricity consumption in agriculture), cropping intensity, fertilizer-use, irrigated area, land use-pattern and literacy level were collected from various publications of the Government of India and respective state governments. Also, time-series data on public funding on research and education and extension in agriculture were taken from the data series compiled by Pal and Singh (1997) and were updated from 1995 onwards to the year 2007-08 and have been reported for further use of researchers (Chand *et al.*, 2011). These data were compiled from the reports of the Comptroller and Auditor General of India for the years 1971-72 to 2007-08.

The Divisia Tornqvist index was used in this study for computing TFP indices for major crops, viz. cereals, pulses, edible oilseeds, sugarcane, cotton, and jute grown in different states of India (For detailed methodological approach on TFP, refer to Kumar, 2001 and Kumar and Rosegrant, 1994). The TFP is influenced by a number of factors such as research, extension, human capital, intensity of cultivation, balanced use of fertilizers, infrastructural facilities, health of natural resources, climate, etc. As an input to public investment decisions, it is useful to understand the relative importance of these yield-enhancing factors in determining productivity growth. To assess the determinants of TFP, the TFP indices were regressed against different variables and the following regression equations were specified:

Model 1

TFP = f (RES_STOK, EXT_STOK, LIT_R, NARI, INF, DUMMY)

Model 2

TFP = g (RES_STOK, EXT_STOK, LIT_R, CI, NPRATIO, IRR_GW, ROAD, ELECT_AG, DUMMY)

where, RES_STOK is the research investment stock per ha of crop area, EXT_STOK is the extension investment stock per ha of crop area, LIT_R is the rural literacy (%), NARI is the natural agricultural resources index, INF is the infrastructural management index, CI is the cropping intensity (%), NPRATIO is the N_2O and P_2O_5 ratio, IRR_GW is the groundwater irrigation index, ROAD is the road density index, and ELECT_AG represents electricity consumption per ha of cropped area. All variables are specified in logarithms, except those variables which are defined in the percentage terms. State dummy variables have been included in both the models.

To estimate returns to research investment, a stream of benefits was generated under the assumption that the investment made in research in the year t-1 will start generating a benefit after a lag of five years, at an increasing rate during the next nine years, will remain constant for the next nine years and thereafter, it will start declining. The returns to research investment were estimated following the procedure suggested by Evenson and Pray (1991). The contribution of agricultural research to crop output has been demonstrated for nine major crops in terms of both quantity and value using tabular analysis. An attempt was also made to quantify the role of research in production and attainment of self-sufficiency in major food commodities of India.

Results and Discussion

TFP Growth for Crops at All-India Level

The estimates of TFP growth for the major crops at all-India level have shown wide variations across crops. Among cereals, wheat experienced the highest growth in TFP during the period 1975-2005 (Table 1). The annual rate of TFP growth was 1.9 per cent for wheat, 1.4 per cent each for maize and barley, 1 per cent for pearl millet, 0.7 per cent for rice and 0.6 per cent for sorghum. The TFP growth in the edible oilseeds varied in the range of 0.7 - 0.8 per cent annually. Among pulses, the TFP growth was estimated to be highest for green gram (0.5%), followed by chickpea (0.2%). For red gram and black gram, TFP displayed a negative growth during this period. Among fibre crops, the TFP rose annually at the rate of 1.4 per cent for cotton and 1.3 per cent for jute during 1975-2005. The TFP growth in sugarcane was found negative (-0.4%).

Using the coefficients of TFP growth, its share in output growth was estimated for the selected crops where TFP growth was positive during the period 1975-2005. The estimated share of TFP growth in output growth ranged between 5 per cent and 74 per cent for various crops — the lowest being for soybean and the highest for jute[1]. More than 50 per cent increase in output of wheat and 24–30 per cent increase in the output of rice, sorghum, pearl millet, barley, chickpea and groundnut were possible through technological change or increase in TFP.

It is believed that a positive change in TFP growth (or technological change) brings a reduction in the real cost of crop production (Kumar and Mruthyunjaya, 1992; Kumar and Rosegrant, 1994). The nominal cost per unit of crop production has shown an upward trend despite growth in productivity. This included the inflationary effect of increase in nominal prices of farm inputs and was removed by estimating the cost at 2005-06 prices and the results for selected crops have been reported in Table 1.

[1] For the crops where the new technology has not induced a higher use of inputs, the output growth is largely because of new technology. Under such a situation, the share of TFP growth in output growth will reflect a higher share in comparison to those crops where the technology induces a higher use of inputs.

Table 1. Annual growth rate in factor productivity, productivity share in output and real cost of production of crops in India: 1975-2005

(Per cent)

Crop	Total factor productivity growth	Productivity share in output growth	Growth in real cost of production
		Cereals	
Rice	0.67	24.6	-1.01
Wheat	1.92	58.9	-2.28
Maize	1.39	16.5	-1.30
Sorghum	0.63	23.7	-2.06
Pearl millet	1.04	27.6	-1.86
Barley	1.38	29.4	-2.07
		Pulses	
Chickpea	0.16	26.1	-1.01
Green gram	0.53	10.0	-1.11
Red gram	-0.69	(-)	0.90
Black gram	-0.47	(-)	0.14
		Edible oilseeds	
Soybean	0.71	5.5	-0.84
Groundnut	0.77	27.1	-1.11
Rapeseed & mustard	0.79	10.1	-1.99
		Other crops	
Sugarcane	-0.41	(-)	-0.36
Cotton	1.41	31.6	-1.62
Jute	1.28	74.1	-1.73

The changes in TFP growth are the significant determinants of average cost of production and income. Accordingly, trend in real cost of production is expected to decline with increase in TFP, other things held constant. The real cost per unit of cereal production has shown an annual decline of 1.0-2.3 per cent, the maximum being in the case of wheat and lowest in sugarcane. Further, in relation to TFP growth, the real cost of pulses production has shown an increase in red gram and black gram and a decline in green gram and chickpea. In the case of edible oilseeds and other crops, the real cost of production has shown an annual decline in the rage of 0.36-1.99 per cent. This has helped in keeping the prices of cereals low for consumers and benefitting the producers also through a decline in cost of production.

Total Factor Productivity Growth at State level

The trends in TFP growth for various crops in different states of India for the period 1975-2005 have been reported in Table 2. In pearl millet, cotton and jute, most of the selected states have witnessed a moderate to high growth in TFP. Similarly, TFP growth in wheat was found positive in all the states, except Himachal Pradesh. In the case of sorghum, half of the states have shown low-to-moderate growth in TFP and the remaining states have depicted a decline in TFP. About one-third of the selected states have experienced a fall in TFP in pulse crops, while Bihar, Rajasthan and Andhra Pradesh have witnessed a high TFP growth in pulses. In rice, a large number of states have depicted low growth in TFP; only Punjab has shown high TFP growth, while Andhra Pradesh and Tamil Nadu have shown a moderate growth in TFP. Out of the sixteen states for which information was available in respect of oilseeds, TFP was found negative in six states, namely West Bengal, Punjab, Haryana, Tamil Nadu, Karnataka and Maharashtra. All the seven states selected for study of sugarcane, have experienced deterioration in its TFP.

Table 2. Trends in total factor productivity growths in various crops in selected states of India: 1975-2005

Crop	Total factor productivity growth category				
	Positive				Negative
	< 0.5% (Stagnant growth)	0.5-1% (Low growth)	1-2% (Moderate growth)	>2% (High growth)	
Cereals					
Rice	Karnataka, Madhya Pradesh, Haryana, Bihar, Odisha, West Bengal	Assam, Karnataka, Uttar Pradesh	Andhra Pradesh, Tamil Nadu	Punjab	
Wheat	Bihar, West Bengal	Madhya Pradesh, Rajasthan	Haryana, Punjab, Gujarat, Uttar Pradesh		Himachal Pradesh
Maize	Madhya Pradesh	Uttar Pradesh	Bihar	Andhra Pradesh	Himachal Pradesh, Rajasthan
Sorghum		Tamil Nadu	Maharashtra, Andhra Pradesh		Madhya Pradesh, Rajasthan, Karnataka
Pearl millet		Uttar Pradesh	Haryana	Rajasthan, Tamil Nadu, Gujarat, Maharashtra	
Pulses					
Gram	Maharashtra, Madhya Pradesh, Uttar Pradesh		Haryana	Bihar	Rajasthan
Green gram			Andhra Pradesh	Rajasthan	Madhya Pradesh, Maharashtra, Odisha
Red gram		Gujarat, Karnataka	Maharashtra, Madhya Pradesh	Andhra Pradesh	Tamil Nadu, Uttar Pradesh, Odisha
Black gram	Maharashtra	Uttar Pradesh	Andhra Pradesh	Rajasthan	Madhya Pradesh, Odisha, Tamil Nadu
Oilseeds					
Rapeseed & mustard	Uttar Pradesh	Assam	Rajasthan	Madhya Pradesh	West Bengal, Punjab, Haryana
Groundnut			Maharashtra, Gujarat, Andhra Pradesh	Odisha	Tamil Nadu, Karnataka
Soybean		Madhya Pradesh, Rajasthan	Uttar Pradesh		Maharashtra
Cash crops					
Sugarcane					Bihar, Karnataka, Haryana, Andhra Pradesh, Maharashtra, Tamil Nadu, Uttar Pradesh
Fibre crops					
Cotton	Punjab	Haryana	Gujarat, Maharashtra	Andhra Pradesh	
Jute	Assam		West Bengal, Odisha, Bihar		

The results relating to TFP growth indicate that much technological gains have not been experienced in a number of crops in many states as they have shown a negative, stagnant or poor growth in the total factor productivity. Only a few states have shown a significant performance of productivity growth which has moved the average productivity gain at the country level to a comfortable position, leading to the impression that technological gains have taken place in almost all the crops at the country level. The disaggregate analysis has also shown that a number of states and crops did not witness any technological progress. Therefore, priority must be focussed on those states which have been observed to be under negative or stagnant TFP growth. If the sustainability issue of crop system as implied by the TFP trend, is not attended properly, it will adversely affect the long-term growth in agriculture as well as the national food-security and household nutritional-security.

Sources of TFP

The TFP can be influenced by factors such as research & extension investment, human resources, cropping intensity, balanced use of plant nutrients, infrastructural development, literacy level, climate, etc. The direction of statistically significant effect on TFP has been presented in Table 3. A perusal of Table 3 reveals that the public investment in research has been a significant source of TFP growth in most of the crops. Public investment in the transfer of technology (extension) has contributed positively towards TFP enhancement in pulses and sugarcane. The variables natural resources management and infrastructure have emerged as important sources of TFP growth for most of the crops. Among natural resources, assured irrigation water along with balanced use of fertilizers, have played a significant role in increasing the TFP level. A look at the infrastructural variables has revealed that road density and electricity supply have been the most significant determinants of TFP. This information is of crucial importance for researchers and policymakers in prioritizing the investment decisions (Fan *et al.*, 1999).

The allocation of additional resources for research, road network, groundwater irrigation, etc. for crops and for states where the current yield levels are below the national average due to technological stagnation or decline, is needed on a higher priority. Public

Table 3. Direction of sources of TFP growth for various crops in India: 1975-2005

Crop	Model 1	Model 2
Rice	Research (+) NARI (+) Infrastructure (+) Electricity (-)	Research (+) N:P_2O_5 ratio (+) Road (+)
Wheat	Research (+) Extension (-) Cropping intensity (+) Road (+)	Research (+) Extension (-)
Maize	Research (+) NARI (+) Infrastructure (-)	Research (+) N:P_2O_5 ratio (+) Electricity (-)
Sorghum	Research (+) Literacy (-)	Research (+) Literacy (-)
Pearl millet	Research (+) Literacy (+) Infrastructure (+) Road (+)	Research (+) Literacy (+) Groundwater (-)
Chickpea	Research (+) Extension (+) Cropping intensity (+) Groundwater (+)	Research (+) Extension (+)
Red gram	Research (+) Literacy (-) NARI (+) Infrastructure (-) Electricity (-)	Research (+) Literacy (-) Cropping intensity (+) N:P_2O_5 ratio (+)
Green gram	Extension (+) Literacy (+) Infrastructure (-)	Extension (+) Road (+) Electricity (-)
Black gram	Extension (+) Cropping intensity (+)	Extension (+)
Groundnut	Research (+) Cropping intensity (+)	Research (+)
Rapeseed & mustard	Research (+)	Research (+)
Sugarcane	Extension (+) Literacy (-)	Extension (+)
Cotton	Research (+) Literacy (+) NARI (-) Groundwater (-) Road (+)	Research (+) Literacy (+) N:P_2O_5 ratio (-)
Jute	NARI (+) Infrastructure (+)	Cropping intensity (+)

NARI=Natural agricultural resource index

Note: Regression models 1 and 2 have been specified under methodology.

Table 4. Elasticity of TFP with respect to research stock for major crops in India

Crop	TFP elasticity with respect to research stock			Research stock flexibility (%)
	Model 1	Model 2	Average	
Rice	0.0454	0.0469	0.0465	21.5
Wheat	0.0513	0.0514	0.0513	19.5
Maize	0.0728	0.0743	0.0734	13.6
Sorghum	0.1128	0.1183	0.1155	8.7
Pearl millet	0.0514	0.0524	0.0519	19.3
Chickpea	0.0986	0.0884	0.0935	10.7
Red gram	0.2148	0.1717	0.1933	5.2
Groundnut	0.0178	0.0192	0.0185	54.1
Rapeseed & mustard	0.0429	0.0505	0.0467	21.4
Cotton	0.0716	0.0857	0.0786	12.7

Note: Regression models 1 and 2 have been specified under methodology

investment in agricultural extension services has not turned up as an important source of TFP growth for a number of crops. One of the reasons for this could be suboptimal investment below the critical level, as the ratio of amount spent on extension to that on research has been falling (Kumar, 2001). As a vast untapped yield potential exists in the country and India is in the process of development of second-generation technologies, much more intensive efforts are required in extension services to disseminate the improved technologies. The slowing down of emphasis on extension services in agriculture will further widen the gap in the adoption and generation of a technology and will induce movement of cropped area towards negative growth or stagnation in TFP. Agricultural extension services need to be strengthened by scaling-up investment levels and by improving their quality. Road density would induce input-output market interface and create a suitable environment for the adoption of technology, and induction of investments in agriculture.

Estimates of regression coefficients which measure the effect of various sources of TFP, were used to compute elasticity of TFP with respect to research stock and to assess the impact of research. The elasticity of TFP with respect to research stock ranged from 0.0185 for groundnut to 0.1933 for red gram (Table 4). The inverse of this elasticity gives research stock flexibility which represents the required increase in research stock to increase in TFP by 1 per cent. These estimates show that to achieve 1 per cent increase in TFP, the investments in research need to be increased by 21.5 per cent for rice, 19.5 per cent for wheat, 19.3 per cent for pearl millet, 13.6 per cent for maize, and 8.7 per cent for sorghum per annum. Among pulses, the research investments will have to be increased by 5.2 per cent for red gram and 10.7 per cent for chickpea per annum. For edible oilseeds, research investments should be increased by 21.4 per cent for rapeseed & mustard and 54 per cent for groundnut to achieve 1 per cent growth in TFP. For cotton, investments on research need to be raised by 12.7 per cent per annum to increase 1 per cent TFP growth. These results suggest a substantial raise in research investments in agriculture to maintain a steady growth rate in TFP. On an average, the investments on research in agriculture need an increase of about 25 per cent annually to achieve 1 per cent growth in TFP.

To achieve 4 per cent growth in agriculture, as targeted by the Planning Commission, a recent study has suggested to lay higher emphasis on the development of livestock, horticulture and fishery sectors besides crop sector. However to achieve 4 per cent growth in agriculture, investments on agricultural research need to be doubled by 2015 and tripled by 2020 in relation to the investment level of 2002 (Mruthyunjya and Kumar, 2010).

Public Funding and Returns to Investment on Agricultural Research

The trends in public funding for agricultural research & education and extension; returns to research investment and the sectoral impact of these investments on agricultural research have been presented in this section.

Trends in Public Funding for Research

Public funding for agricultural research is an important factor which affects the development of agriculture. The amount of research funding and mode of its allocation are powerful tools of research policy in India as elsewhere. In India, the majority of funds for agricultural research are allocated through block grants, but funding through competitive grants has also gained momentum in recent years. There has been a significant increase in public funding for agricultural research and education (R&E) and extension during the past three and a-half decades. Data revealed that public funding for agricultural R&E increased from ₹ 37.8 crore in 1971-72 to ₹ 4308 crore in 2007-08, an increase of 113-times (Figure 1). The figure clearly shows a sustained increase in public funding for agricultural R&E from the early 1980s onwards. It increased from ₹ 187.5 crore in 1981-82 to ₹ 770.5 crore in 1991-92, ₹ 2537 crore in 2001-02 and then to ₹ 3681 crore in 2005-06. It further rose to ₹ 4308 crore in 2007-08.

Another way to assess the funding for research is to compute an intensity ratio such as research expenditure as the percentage of agricultural gross domestic product (AgGDP). This ratio increased significantly from 0.21 per cent to 0.62 per cent during 1971-2008, but remained around 0.6 per cent during 2000s.

The share of public expenditure on agricultural extension has not shown any specific trend and it has been only around 0.14 per cent of the AgGDP. This low level of research intensity is a cause of worry given its 1 per cent level globally. Also, the emerging complex challenges require higher investment on research for their addressal. The funding on R&D denotes the capacity to use science in promoting productivity growth to achieve food security and reduce poverty and hunger. It is noted that for agricultural output of every US$ 100, developed countries spend US$ 2.16 on public agricultural R&D, whereas developing countries hardly spend US$ 0.55 (Beintema and Stads, 2008).

Returns to Investment on Research in Agriculture

The analysis of returns to research investment shows the direction of returns. It has provided justification for the previous fundings and has presented a sound basis for future funding, based on the level of returns. Analysis has shown that the rate of returns to research investment was higher during 1995-2005 than during 1985-95 in all crops, except wheat and oilseeds (Table 5). These results have clearly brought out that the future investments on research in agriculture will provide reasonable returns and will lead

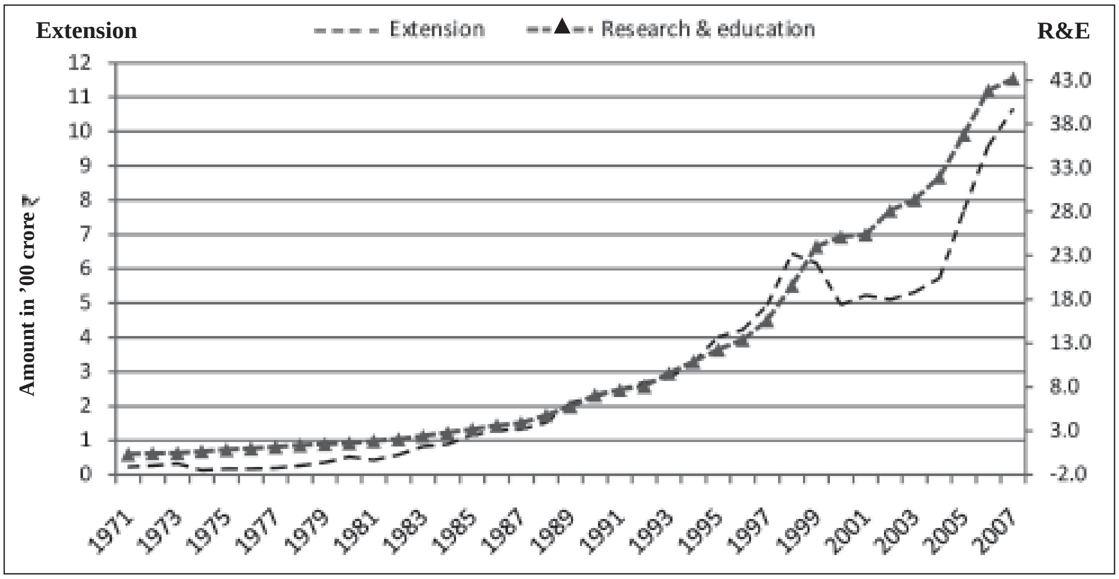

Figure 1. Trends in public funding for agricultural research & education and extension in India (at current prices): 1971-2007

Table 5. Internal rate of return to research investment in different crops of India: 1975-2005

(per cent)

Crop	1985-95	1995-05	1975-2005
Rice	28	31	29
Wheat	44	36	38
Maize	25	32	28
Sorghum	34	44	39
Pearl millet	19	35	31
Chickpea	20	38	34
Red gram	54	59	57
Groundnut	19	17	18
Rapeseed & mustard	17	33	20
Cotton	33	38	39

to agricultural development in the country. During the period 1975-2005, the overall internal rates of return (IRR) to public investment in agricultural research were highest for red gram (57%), followed by sorghum and cotton (39% each), wheat (38%), chickpea (34%), pearl millet (31%), rice (29%), maize (28%), and were lowest for groundnut (18%).

Sectoral Impact of Investment on Agricultural Research

The rates of return to public investments on research in agriculture were computed using macro level data on output and input in the agriculture sector comprising crop and livestock, obtained from National Accounts Statistics, Government of India, for the period 1985-86 to 2006-07.

The growth in agricultural output for the period 1985-2006 was estimated to be 2.92 per cent against the input growth of 2.39 per cent, resulting in 0.53 per cent growth in TFP (Table 6). The TFP share in output growth was estimated to be 17.8 per cent during this period. Almost a similar trend was noticed for the period 1990-2006. However, growth in TFP and its contribution to output growth as well as the internal rate of returns (IRR) to public research investment in agriculture have all declined, though marginally since early-1990s. But the impact seems to be quite high, IRR being 42 per cent even in the recent period (1990-2006).

Contributions of Agricultural Research

Contribution to Crop Output: Quantity and Value

The concerted efforts in agricultural R&D have helped in up-scaling the productivity potential and generated higher income at lower cost per unit of output (Kalirajan and Shand, 1997). Generally, adoption of any new technology/innovative process raises the yield frontier, lowers the production cost per unit of output, and provides more income. The share of TFP growth in output growth has been found in the range of 10.1 per cent for rapeseed & mustard to 58.9 per cent for wheat (Table 7). The share of agricultural research in TFP growth has been estimated to be 88.6 per cent for rapeseed & mustard, 79.2 per cent for maize, 78.4 per cent for pearl millet, 55.7 per cent for paddy, 42.2 per cent for chickpea, 40.1 per cent for wheat, 36.0 per cent for groundnut and 26.4 per cent for cotton. These two sets of numbers in shares were multiplied to arrive

Table 6. Productivity growth and returns to research investment in agriculture (crops and livestock) in India: 1985-2006

Particulars	During the period	
	1985-86 to 2006-07	1990-91 to 2006-07
Growth in agricultural output (%)	2.92	2.80
Growth in inputs used in agriculture (crops and livestock) (%)	2.39	2.38
Growth in total factor productivity (%)	0.53	0.42
Share of TFP in output growth (%)	17.80	14.70
Elasticity of TFP with respect to research investments*	0.296	0.296
Internal rate of return to research investments in agriculture (%)	46.0	42.0

*From Fan *et al.* (1999)

Table 7. Contribution of agricultural research investment to output of major crops in India: 2005-06

Particulars	Paddy	Wheat	Maize	Sorghum	Pearl millet	Chick-pea	Ground-nut	Rapeseed & mustard	Cotton
Share of TFP in output growth (%)	24.5	58.9	16.5	23.7	27.6	26.1	27.1	10.1	31.6
Share of research in TFP growth (%)	55.7	40.1	79.2	27.8	74.8	42.2	36.0	88.6	83.6
Share of research in output growth (%)	13.6	23.6	13.1	6.6	20.6	11.0	9.8	8.9	26.4
Crop production growth (%)	2.3	3.5	2.9	0.3	1.7	0.6	0.8	4.5	3.1
Contribution of research to production growth (percentage point)	0.32	0.83	0.38	0.02	0.36	0.07	0.08	0.40	0.8
Production in 2005-06 (Mt)	133.47	69.35	14.71	7.24	7.68	5.60	7.99	8.13	18.5
Contribution of research to production (Mt)	0.4228	0.5896	0.0555	0.0016	0.0287	0.0039	0.0054	0.0310	0.1575
Price in 2005-06 (₹/q)	570	1080	525	525	525	1435	1520	1715	3570
Contribution of research to selected crops (in crore ₹)	241.0	636.8	29.1	0.8	15.1	5.6	8.2	53.2	562.4

at the contribution of research to production growth. Based on these estimates it was observed that about one-fourth growth in output of wheat and cotton, one-fifth in the case of pearl millet and nearly 13 per cent in paddy and maize were due to investments on research in agriculture. In most of the other crops, about one-tenth of output growth was achieved due to public investment on research in agriculture, the lowest being 6.6 per cent in the case of sorghum.

The estimates of research contribution to production growth were further used to get an idea about the contribution of research to incremental output of food commodities in a given year. The contribution of agricultural research investment to output growth of selected nine crops has been presented in Table 7 as an illustration for the year 2005-06. The growth rate in production of a given crop was used for the period 1975-76 to 2005-06 for assessing the contribution of research to agricultural production. During this period, the output of paddy increased by 2.32 per cent each year in which 0.32 percentage point growth was due to research in agriculture. This implies that 0.32 percentage growth in paddy output during 2005-06 was due to research which amounts to 0.4228 Mt in terms of quantity. Valued even at the minimum support price, this incremental output is worth ₹ 241 crore. This does not include the research contribution in improving the quality which fetches a premium price for traits like fine grain or improved varieties of basmati rice. Similarly, the contribution of research to wheat output during 2005-06 was estimated to be 0.5896 Mt; it is valued at ₹ 636.8 crore. Cotton crop ranked next to wheat in terms of contribution of research; it is valued at ₹ 562 crore.

The contribution of agricultural research in the value of output of the nine selected crops has been computed as ₹ 1552 crore (Table 8). These nine crops together accounted for about 41 per cent of the value of crop output in 2005-06. If the crops not included in the study also experience a similar growth in TFP and have the same contribution of research to TFP growth as is the average of these nine crops, then the contribution of research to Indian agriculture comes to be ₹ 3748 crore for the crop sector alone (Table 8). This contribution is 33 per cent higher than the annual research investment made in the crop sector by the public sector in the country. The study has thus clearly shown that the investment on research in agriculture

Table 8. Contribution of agricultural research to crop sector in India: 2005-06

Particulars	Value
Contribution of research to selected 9 crops (Table 7) (in crore ₹)	1552
Share of selected crops in value of production from agriculture (%)	41.4
Contribution of research to crop sector based on the selected crops (in crore ₹)	3748
Research investment in the year 2005-06 (in crore ₹)	2814
Returns to research investment (%)	33.2

is a highly paying proposition and presents a strong case for additional allocation of resources for the development of agriculture in the country and attainment of national food and nutritional security.

Contribution of Agricultural Research to National Food Self-sufficiency Attainment

An important contribution of output growth achieved through research in agriculture is the reduction in import dependency for meeting the food requirement of the nation and thus improving national food self-sufficiency. Estimates of contribution of research to output growth obtained in the study were used to quantify the contribution of research to the attainment of self-sufficiency in various crops.

Between TE 1975 and TE 2005, the incremental production was of 46 Mt in rice, 44 Mt in wheat, and 8.3 Mt in maize. For other food crops included in the study, the additional increase in the production volume was relatively small (Table 9).

The incremental production was multiplied with the share of research in production growth to arrive at the incremental production due to research. It has been estimated that in the absence of contribution of agricultural research, production in the country in 2005-06 would have been lower by 10.4 Mt in wheat and by 6.3 Mt in rice (Table 9). The contribution of research to additional production of maize and pearl millet has been estimated to be 1.09 Mt and 0.64 Mt, respectively. As there has been a decline in the production of sorghum over time, it was not considered meaningful to compute contribution of research to sorghum production. The cumulative effect of research in agriculture on output of chickpea has been estimated as 80 thousand tonnes. In oilseeds, groundnut production would have been lower by 80 thousand tonnes and rapeseed & mustard production would have turned 5.2 lakh tonnes lower without the contribution of agricultural research. Thus, in the absence of research support, the respective output of rice and wheat would have been 85.5 Mt and 60.9 Mt instead of the actual production of 91.8 Mt and 69.3 Mt in the year 2005-06. Similar changes would have happened in other agricultural commodities also (Table 9).

In all the commodities, the domestic demand in the year 2005-06 was much higher than what would have been the total production in the country without the contribution of research. Under that scenario, India would have been far away from the attainment of self-sufficiency in food. The exact impact of research on self-sufficiency of the selected crops was analyzed and is presented in Table 9. A comparison of domestic demand with domestic production adjusted for trade and change in stock has shown that the domestic production of wheat in the year 2005-06 was enough to meet 98 per cent of the country's demand. Without contribution of research, self-sufficiency attainment in wheat would have declined to 83.4 per cent. This implies that India would have been forced to import 9.8 Mt of wheat in the absence of research contribution during the past three decades. In rice, India exports about 5 per cent of its domestic production and thus the ratio of production to demand is 105.14 per cent. This ratio declines to 97.9 per cent when incremental output due to research is not counted. Thus, without contribution of research to rice production, India would have been forced to import 1.77 Mt of rice, after wiping out the export of 4 Mt rice. The contribution of research to attainment of self-sufficiency in maize and pearl millet has been found to be around 8 per cent.

India is not self-sufficient in the production of pulses and edible oils and the gap between domestic demand and production is met through imports. The contribution of research has not made a significant difference in the level of self-sufficiency attainment in chickpea and groundnut. In the case of rapeseed & mustard, import dependency of India would have

Table 9. Contribution of agricultural research to production and attainment of self-sufficiency in major food crops in India

Particulars	Rice	Wheat	Maize	Sorghum	Pearl millet	Chickpea	Ground-nut	Rapeseed & mustard
Incremental production between TE1975 and TE-2005 (Mt)	46.0	44.0	8.3	-2.9	3.1	0.7	0.8	5.8
Share of research investment in production growth (%)	13.6	23.6	13.1	6.6	20.6	11.0	9.8	8.9
Production in 2005-06 (Mt)	91.8	69.4	14.7	7.2	7.7	5.6	7.9	8.1
Incremental production due to research (Mt)	6.3	10.4	1.1	-	0.6	0.1	0.1	0.5
Likely production without contribution of research investment (Mt)	85.5	60.9	13.6	7.4	7.4	5.7	6.5	7.2
Domestic demand in 2005 (Mt)	87.3	70.7	14.2	7.2	7.7	6.4	12.1	12.3
Self-sufficiency attainment (%)								
Actual (2005-06)	105.1	98.1	103.9	100.0	100.0	88.0	66.3	66.2
Without contribution of research	97.9	83.4	96.3	-	91.7	86.8	65.6	61.9
Contribution of research	7.2	14.7	7.7	-	8.3	1.2	0.7	4.2
Dependence on import without contribution of research (Mt)	1.8	8.9	0.6	-	0.3	0.7	5.6	5.1

increased from 34 per cent to 38 per cent without the contribution of public sector research to growth of output of rapeseed & mustard.

Conclusions and Policy Implications

Investments made on agricultural research in the country with the onset of green revolution during the mid-1970s helped in the development and promotion of green revolution technologies (GRTs) which had a high payoff. Initially, the spread of GRTs was confined to a limited area but after mid-1980s, the country witnessed the spread of GRTs to a wider area which continued through the early years of 1990s. However, the productivity growth attained during the decades of 1975-95 could not be sustained during 1995-2005. Also, the benefits from GRTs have not been similar for all crops across different states of India. During 1995-2005, the crop sector experienced diminishing returns to input-use and a significant proportion of gross cropped area is facing deceleration or stagnation in the TFP growth. This has resulted from a number of factors which need to be addressed.

The productivity performance, measured by the growth in TFP, has shown considerable variations across crops and regions. Wheat has enjoyed the highest benefit of technological change during the period 1975-2005 with its annual TFP growth close to 2 per cent. Rice lags far behind wheat and has witnessed annual TFP growth of only 0.67 per cent. Major cereals, namely wheat and paddy have experienced a lower growth in TFP after mid-1990s. Maize on the other hand, has shown accelerating growth of 1.64 per cent during this period. Despite lot of claims about hybrid sorghum, its TFP growth has shown a decline during 1995-05. In contrast, the TFP growth in pearl millet, which is entirely a rainfed crop, has been highly impressive. More than half of the total growth in output of wheat and around one-fourth in other cereals have been contributed by the growths in respective TFP.

Except green gram, all other major pulse crops have shown either stagnation or decline in the TFP growth, indicating that these crops have not benefitted from the technological gains; even the current trends in their production are not impressive and difficult to sustain. In oilseeds, rapeseed & mustard has experienced a strong technological growth during 1975-85, which halved during 1986-95 and reached almost zero during 1996-2005. The TFP growth in groundnut has followed improvement in each decade after 1985. The growth for soybean has remained below 1 per cent. Sugarcane production has shown a declining productivity after 1985, indicating that growth in its output is getting increasingly difficult. There was a deceleration in the TFP growth of cotton and jute after 1985 which continued till 2005.

At the state level, the highest growth in TFP in rice production has been experienced in Punjab, followed by Andhra Pradesh during the period 1975-05. The western states of the country including Madhya Pradesh, have benefited a little from the technology and infrastructure-related factors in rice output. Except Himachal Pradesh, all wheat-growing states have benefited from the TFP growth with Gujarat at the top. Technology has brought substantial growth and efficiency in maize production in Andhra Pradesh. Sorghum production and contribution of technology to it have shown deterioration in the selected states, except Maharashtra which has benefited from the technological change in a big way. Despite its lackluster performance at the national level, rapeseed & mustard has performed very well with the support of technology in Gujarat, Madhya Pradesh, Rajasthan and Odisha. In soybean, though Madhya Pradesh has experienced an unprecedented growth in output, the role of technology in output growth has been merely 4 per cent.

The disaggregate analysis has shown that some crops and states did not witness any significant technological change. There is an urgent need to focus on research and extension for those states which fall under the negative or low TFP growth. This will help in boosting long-term growth as well as improving national food-security and household nutritional-security.

The technology-led output growth has also helped in a decline in real cost of production in the range of 1.0-2.3 per cent per annum during the past three decades in the case of cereals. This has helped in keeping the prices of cereals low for consumers and providing benefits to producers through a decline in real cost of production.

The contribution of agricultural research in reducing dependency on import and improving the self-sufficiency of important cereals including their large reserves is well known and is cited with pride. In terms of figures, agricultural research carried out during past three decades (1975-05) has improved the self-sufficiency status in wheat by 15 per cent and in rice by 7 per cent. The growth in food production induced by research has not only reduced the import dependency but has also added to export capacity, amounting to 17 Mt of cereals. In value terms, it comes to more than four-times the annual investment on agricultural research in the country. It has also reduced pressure on globally traded food commodities. In the absence of contribution of research to Indian agriculture, the global supply of rice and wheat (quantity available for export) would have reduced by about 12 per cent. This could result in a sharp increase in global grain prices, causing adverse effect on food security of a large number of low-income food-deficit countries.

In order to sustain food security and achieve the projected rise in production of food and non-food commodities, essentially through enhancing yield per unit of land, India needs to maintain a steady growth rate in TFP. As TFP increases, the cost of production decreases and consequently, prices fall and stabilize at a lower level. Therefore, both producers and consumers are benefited.

The public policies such as investment in research, education and extension, infrastructure, and natural resource management have been the major sources of TFP growth. Increase in agricultural investments, especially in agricultural research, is urgently needed to stimulate growth in TFP. To attain 4 per cent agricultural growth, as targeted by the Planning Commission, at least one-third of this growth must come through technological innovations and remaining two-thirds has to be achieved through additional use of agricultural inputs. To meet these targets, investments on agricultural research need to be doubled by 2015 and tripled by 2020 in relation to the investment level of 2002.

The slowing-down of emphasis on agricultural extension has widened the gap in the adoption and generation of technology. And therefore, there is an immediate need to strengthen the extension services by scaling-up investment levels and improving its quality. The first step in this direction should be an increase in the availability of operating funds for extension activities in agriculture. It will accelerate the TFP growth, improve the sustainability of the crop sector and minimize the yield gap across regions of the country.

Since 2002-03, the government spending on research and education in agriculture has stagnated at around 0.6 per cent of agricultural GDP. The share of agricultural GDP spent on agricultural extension has not shown any specific trend. In recent years, the government has spent only about 0.14 per cent of agricultural GDP on extension services. Contribution of agricultural research to attainment of self-sufficiency in food and growth in TFP as well as high payoff to investment in agricultural research and extension are strong justifications for adequate funding for research and extension in agriculture. It requires a big jump in allocation of public resources to agricultural research system of the country, as brought out in the present study.

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