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Impact of Total Factor Productivity and Return to Investment on Research for Sustainable Agriculture Growth: A Case Study of South Gujarat Region

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ABSTRACT
TFP growth in South Gujarat by crops has developed a strong perception that technological gains occurred in paddy, wheat, tur, cotton, sugarcane, and banana.Cotton has enjoyed the highest benefit of technological innovations during the past twenty-four years with its TFP growth more than 3per cent. The impact of research on different crops has indicated high payoffs to research in all crops. The results revealed that investment of rupee one in research stock has generated, on an average, an additional income of Rs 7, indicating high rates of returns to public investments. The marginal internal rates of return to agricultural research are estimated to be between 35 and 54 per cent showing that investment in agricultural research during the past 24 years has resulted in attractive returns. The study has clearly indicated that investment in agriculture is a highly paying proposition and presents strong case for allocation of additional resources to research for the development of agriculture in South Gujarat.

Keywords
AgGDP, agriculture research, Divisia Tornqvist, IRR, MIRR, NARS, TFP

JEL Codes
C32, C82, O33, Q16, Q18

INTRODUCTION

Research has been the prime mover of agricultural growth across the globe including India. In the *post-Green Revolution* period, productivity growth was sustained initially through increased input-use, and later through input efficiency-enhancing technological changes. The Indian National Agricultural Research System (NARS) is one of the largest networks in the world, with an outlay of about 0.6 per cent of national agricultural gross domestic product (AgGDP) (Mruthyunjaya *et al.,* 1995).

India has made huge public investments on agricultural development particularly on research, extension, and irrigation. And therefore concerns are being raised in India, as elsewhere in the developing economies, as to whether the investments in research and extension still generate any returns. The magnitude of returns to public investment is particularly important for India in the period of policy reforms and economic liberalization. This period of economic reforms is accompanied by budgetary constraints which necessitate a careful monitoring of public investment funds, raising a basic question whether India needs to continue huge public expenditures on agriculture. These concerns are heightened by the perception that the returns to investment on agricultural research and irrigation may be declining over time because the "easiest" gains from the green revolution have already been reaped through the rapid spread of modern crop varieties particularly of wheat and rice, leading to high levels of their adoption and application of high levels of inputs in many regions of India. The failure of domestic and foreign research to generate crop varieties with yields higher than of varieties developed in 1960s and the increasing capital costs on irrigation are other aspects of concerns. Economic liberalization has also heightened the importance of private sector activities in promoting productivity growth in India. It is therefore quite important to understand the magnitude of social benefits of public investment on research in agriculture (Rosegrant and Evenson, 1995).

Some of the issues before agricultural R&D investment are: Are the returns to investment in agricultural research in South Gujarat still high or declining? What has been the contribution of productivity growth to total output growth? What have been the sources of productivity growth? What is the impact of research on productivity growth? To address these issues, this study has assessed the Total Factor Productivity (TFP) growth in South Gujarat, has examined the sources of productivity growth, including public investment, and has estimated the rates of return to public investments in agriculture.

Concept of Total Factor Productivity

Productivity measurement is essential to account for economic growth. The efficiency change analysis of Total Factor Productivity (TFP) attempts to measure the increase in total output which is not accounted for by the increases in total inputs. In the production function framework, TFP growth indicates technological progress, which represents shifts in the production function over time. In the context of India, technological progress measures the impact of shifts in production on account of irrigation, high-yielding varieties (HYVs), modern agricultural equipment, fertilizers, pesticides, etc. It also captures the effects of improved labour quality, better management practices, and intensive use of resources which lead to increased crop intensity, changes in cropping pattern in favour of high value-added crops, etc.

The Total Factor Productivity (TFP) is the portion of output not explained by the amount of inputs used in production. As such, its level is determined by how efficiently and intensely the inputs are utilized in production (Comin, 2006).

Growth in TFP

India has one of the largest and most complex agricultural research systems in the world, with more than a century of organized application of science to agriculture. Public funding to research in India has consistently increased in all fields of science, including agriculture. The NARS in India has been relatively successful in increasing government funding for R&E. However, the current funding allocation is not sufficient, for a number of reasons. First, funding has not kept pace with the increasing number of R&E institutions, second the share of salary and overhead expenditures has gradually increased at the expense of research expenditures (Pal and Singh 1997).

The ratio of salary to operational expenses has increased to 70:30 in ICAR, compared with the target of 60:40; and the situation is even more serious for the state agricultural universities (SAUs). The intensity of state funding has increased in all states, except West Bengal since the 1980s. However, wide variations persist across states with comparatively high ratios, over 0.4per cent of AgGDP (Himachal Pradesh, Tamil Nadu, Haryana, Maharashtra, Gujarat, and Kerala) and states with very low ratios, under 0.2 per cent (Madhya Pradesh, Rajasthan, Uttar Pradesh, and West Bengal) (Pal and Byerlee, 2006).

Economic Impact of Research Investments

There is massive evidence from all over the world, both from developed as well as developing countries, indicating that agricultural research is one of the most rewarding investment options.

Table 1: Estimated internal rates of return to investment on agricultural research in India

Category/study	Year	Crop	Period	Estimated marginal internal rate of return (EMIRR) (per cent)
Evenson and Jha	1973		1953-71	40
Kahlon *et al.*	1977		1960-73	63
Evenson and McKinsey	1991		1958-83	65
Rosegrant and Evenson	1992			62
Tabor *et al*.	1998		1956-87	58
Evenson and McKinsey	1991	Rice	1954-84	155
		Wheat	1954-84	51
		Jowar	1954-84	117
		Bajra	1954-84	107
		Maize	1954-84	94
Evenson *et al.*	1999		1977-1987	62
Thirtle *et al.*	2003		1985-1995	24

Sources: Ramasamy and Selvaraj (2005), Evenson et al. (1999)

Several studies have estimated the changes in TFP and the share of that change which could be attributed to agricultural R&D investments. Evenson *et al.* (1999) have identified ten ex-post studies on the returns to aggregate research programs in South Asia. Seven of these, plus a more recent study by Thirtle *et al.* (2003), extend into the post-GR era and are summarized in Table 1. Despite some differences in methods of analysis and time periods covered, all the studies show rates of return that are much higher than any reasonable discount rate. Fan *et al.* (1999) have used a simultaneous equations model to estimate the returns to public investments in agricultural R&D in India. In addition to controlling the other types of public investments (necessary to avoid biasing the estimated returns to research), this approach has the added advantage of giving comparative returns between different types of public investments. They have reported that public investments in agricultural research have yielded the highest productivity returns in recent decades, with the benefit–cost ratio as high as 13.5 (Table 2). It is more than double the benefit–cost ratio for the next best public investment – rural roads, and more than 10-times the ratios for education, irrigation, and rural development.

Fan *et al.* (1999) have also found that the marginal benefits of R&D investment in India show little sign of diminishing over time, unlike some other public investments. This is confirmed by Evenson *et al.* (1999) in a study of the determinants of growth in India's agricultural TFP from 1956 to 1987.

Table 3 summarizes the rates of return estimated for a range of agricultural commodities reported by the studies published since 1985. The rates of return range from 20 to 155 per cent with average of 60per cent. These rates are also consistent with the high average returns reported in the literature for Asia: Evenson (2001) has reported an average rate of return of 67 per cent and Alston *et al.* (2000) have reported an average rate of 49.6 per cent (median 78.1 per cent). Alston *et al.* (2000) and Evenson *et al.* (1999) have found no evidence that rates of return are declining over time. Going beyond rate of return calculations, Fan (2007) has estimated that India's rice variety improvement work contributes about US$ 3–4 billion per year to national rice production (at constant 2000 prices), which is considerably greater than the total annual cost of the national R&D system. Using some plausible and alternative attribution rules, Fan has also estimated that IRRI's rice improvement work can be credited with between 12 and 64 per cent of India's US$ 3.6 billion gain in 2000 (a gain of between US$ 432 million and US$ 2304 million), and with 40-80 per cent of the US$ 3.9 billion gain in 1991 (a gain of between US$ 1560 million and US$ 3120 million). He has noted that IRRI's contribution has diminished since 1991 but is still far more each year than is needed to justify the institute's entire research budget. Indeed, in both years it was enough to cover the annual cost of the CGIAR's entire global program.

Table 2: Productivity and poverty effects of government investments in rural India

Expenditure variable	Productivity returns in agriculture in rupees (₹) per ₹ invested	Number of people lifted out of poverty per million ₹ invested
Rand D	13.45	84.5
Irrigation	1.36	9.7
Roads	5.31	123.8
Education	1.39	41.0
Power	0.26	3.8
Soil & water	0.96	22.6
Rural development	1.09	17.8
Health	0.84	25.5

Source: Fan and Rao (2008)

Lantican *et al.* (2005) have estimated that the additional value of wheat production in developing countries attributable to international wheat improvement research ranges from US$ 2.0 billion to US$ 6.1 billion per year (2002 dollars). They have not provided a regional allocation of these benefits, but assuming that benefits are shared in rough proportion to the share of the world wheat area grown, South Asia captures about 28 per cent of the benefits, or US$ 560–1710 million per year. Similarly, Morris *et al.* (1992) have estimated that the economic benefits to the developing world from using CIMMYT-derived maize germplasm fall in the range US$ 557–770 million each year. Again they have not provided a regional allocation of these benefits, but assuming that benefits are shared in rough proportion to the world share of the area.

Indian NARS has made significant contributions in multiple ways to agricultural and non-agricultural sectors. It is reflected in improvement in productivity and high benefit-cost ratio of almost all cultivated crops; increase in social welfare in terms of food security and poverty reduction; and better awareness about the need for conservation of natural resources. It has been shown empirically that the investment in agricultural research and extension is the main source of growth as exhibited by the robust Total Factor Productivity (TFP) and comfortable rates of return to agricultural research investment in Indian agriculture (Evenson and McKinsey, 1991; Kumar and Rosegrant, 1994). Various studies conducted during the different time periods have shown that marginal internal rate of return to agricultural research and investment is highly rewarding. Estimated elasticity of agricultural research expenditure by public sector on agricultural GDP is highly significant, showing that 10 per cent increase in public sector expenditure on agricultural research and development would induce agricultural growth by 2.4 per cent at constant prices. Similarly, crop-wise analysis has also indicated that R&D -induced supply shift in major

Table 3: Estimated internal rates of return to crop improvement research in South Asia

Study	Country	Commodity	Period	Rate of return per cent
Nagy (1985)	Pakistan	Maize	1967-1981	19
		Wheat		58
Morris *et al*. (1 992)	Nepal	Wheat	1966-1990	37-54
Evenson and McKinsey (1991)	India	Rice	1954-1984	155
		Wheat		51
		Jowar (Sorghum)		117
		Bajra (Pearl miilet)		107
		Maize		94
Byerlee (1993)	Pakistan	Wheat	1971-1988	50-57
Azam *et al*. (1991)	Pakistan	Wheat	1956-1985	76
		Rice		84
		Maize		45
		Bajra (Pearl miilet)		42
		Jowar (Sorghum)		48
Collins (1995)	Pakistan	Wheat		60-71
Iqbal (1991)	Pakistan	Rice	1971-1988	50-57
Byerlee and Traxler (1995)	South Asia	Wheat (Spring)		91
Hossain (1998)	Bangladesh	Rice	1973-1993	16.6
Joshi and Bantilan (1998)	India	Groundnuts (improved variety plus RBF)		13.5-25.2
Bantilan and Joshi (1996)	India	Pigeonpea (wilt resistance)	1986-2005	61
Ramasamy *et al.* (2000)	India	Pearl millet	1970-2000	27
Mittal and Kumar (2005)	India	Wheat	1976-1980	65.5
			1986-1990	67.8
			1991-1995	61.1
Thorat *et al.* (2006)	India	Horticulture crops	1981-2000	119
Chand *et al.* (2011)	India	Rice	1975-2005	29
		Wheat		28
		Maize		39

crops (Ramasamy and Selvaraj, 2005).

The growth in agricultural output in India has remained of active interest to researchers and policymakers since long. There have been various attempts made to capture pay off from agricultural research at India and State. However, such attempts at the regional level particularly at South Gujarat have not been made so far. There is need to understand whether the agriculture and horticulture research & development activities have contributed to agriculture output in the region. First systematic study by Minhas and Vaidyanathan (1965) and later, work on the decomposition of growth in agricultural output became more refined and invoked the 'partial productivity' concept. Studies by Evenson and Jha (1973) and later followed by Sidhu and Byerlee (1992); Kumar and Mruthyunjaya (1992); Rosegrant and Evenson (1992); Dholakia and Dholakia (1993); Kumar and Rosegrant (1994); Ranjitha (1996); Evenson *et al.* (1999); Fan *et al.* (1999); Ali and Byerlee (1999); (Kumar, 2001); Coelli and Rao (2003); Rozelle *et al.* (2003); Joshi *et al.* (2005); Mittal and Kumar (2005); Thorat *et al.* (2006); Chand *et al.* (2011), and few others have been listed in the text on this genre.

DATA BASE AND METHODOLOGY

The present study carried out in south Gujarat region. For the accomplishment of the objective, secondary data on yield, use of inputs and their prices were collated from the Comprehensive Scheme on the Study of "Cost of Cultivation of Principal Crops" (CCPC) grown in South Gujarat were used in the analysis. The data were collected for the period 1986-87 to 2009-10. Data on input quantity and its value were available for all the variables except insecticides, for which indirect method was used to compute the quantity. The missing year data on inputs and their prices were estimated using interpolation based on trends in the available data. This dataset was a rich resource for estimating and analyzing agricultural productivity in the selected area. The time-series data on infrastructural variables (road and rail density, consumption of electricity in agriculture), cropping intensity, fertilizers, irrigated area, land-use pattern and literacy were collected for different districts of South Gujarat from various publications of Govt. of Gujarat and respective district agriculture departments. Eight major crops, viz. Paddy, Wheat, Shorgum, Tur, Gram, Cotton, Sugarcane and Banana, were included in the study. Farm harvest prices were used to aggregate the outputs. The study was conducted in the South Gujarat region of Gujarat state which comprises seven districts, viz. Navsari, Surat, Valsad, Tapi, Dang, Bharuch, and Narmada. All these seven districts are under jurisdiction of Navsari Agricultural University, Navsari (Gujarat).

Measurement of Total Factor Productivity (TFP)

The increased use of inputs, to a certain extent, allows the agricultural sector to move along the production surface. The use of modern inputs may also induce an upward shift in the production function to the extent that a technological change is embodied in them. The Total Factor Productivity (TFP) captures the increase in total output which is not accounted for by the increases in total inputs. The Total Factor Productivity index is computed as the ratio of an index of aggregate output to an index of aggregate inputs. Growth in TFP is therefore the growth rate in total output less the growth rate in total inputs. In this study, the Divisia-Tornqvist index was used to compute total output, total input, TFP and input price indices for selected crops. One of the most defensible methods of aggregation in productivity measurement is Divisia aggregation. Divisia indices have two important characteristics: (i) They satisfy the time reversal and factor reversal tests for index numbers, and (ii) There are discrete of the components, so that aggregate could be obtained by the aggregation of sub-aggregates. For discrete data, the most commonly used approximation to the (continuous) Divisia index is the Tornqvist approximation. Grain and straw from crops were included in the output index. Farm harvest prices were used to aggregate the outputs. Land, seed, fertilizer, manure, pesticide/herbicides, human labour, animal labour, machine labour, irrigation, etc. are included in the input index. Inputs were aggregated using farm rental prices.

The total output, total input, TFP and input price indices, calculated for different crops, are as follows:

Total Output Index (TOI)

$$TOI_t / TOI_{t-1} = {}_j(Q_{jt} / Q_{jt-1})^{(R_{jt} + R_{jt-1})^1/2}$$

Total Input Index (TII)

$$TII_t / TII_{t-1} = {}_i(x_{it} / x_{it-1})^{(S_{it} + S_{it-1})^1/2}$$

where,

R_{jt} is share of the 'j' th output in total revenue,

Q_{jt} is output of the 'j' th commodity,

S_{it} is share of the 'i' th input in total input cost,

x_{it} is quantity of the 'i'th input, and

t is the time period

For productivity measurement over a long period of time, chaining of indices for successive time periods is preferred. With chain-linking, an index is calculated for two successive periods, t and t-1, over the whole period from 0 to T (sample from time t=0 to t=T) and the separate indices are then multiplied together:

TOI (t) = TOI (1).TOI(2)………………TOI(t-1)

TII (t) = TII (1).TII(2)………………TII(t-1)

Using TOI (t) and TII (I), the Total Factor Productivity (TFP) index was calculated as:

$$TFP_t \quad \frac{TOI_{(t)}}{TII_{(I)}}$$

Chain-linking index takes into account the changes in relative values/costs throughout the period of the study. This procedure has the advantage that no single period plays a dominant role in determining share weights and biases are likely to be reduced. The above equations were used to get the indices of total output, total input, and TFP for the specified year 't'.

TFP trend indicates whether production growth is taking place in a cost-effective and sustainable manner. While growth in output can be achieved by using higher and higher levels of inputs, it may not be sustainable in the long-run if incremental output involves increasing doses of incremental inputs. The sustainable growth in the long-run necessitates a higher growth in output compared to inputs. It serves as an excellent indicator of the performance of any production system and sustainability of the growth process. It overcomes the limitations of partial input productivity measures as well as partial output productivity, especially when the production of one activity affects the production of other activities. TFP is influenced by the changes in technology, institutional reform, infrastructural development, human resource development and other factors. The crop-related technology changes that are often embodied in seed adoption by the farmer can be divided into two components: "quality", and "quantity". The former represents productivity improvement and cost reduction, while the latter is the extent of area on which the farmer adopts the technology. The "quality" reflects the research output that is determined by the investment in research and is an exogenous variable in explaining TFP. The "quantity" of technology is linked to its adoption and is affected by the extension, literacy, infrastructural development, as well as on-farm and off-farm characteristics (Kumar *et al.,* 2008).

Sources of TFP Growth

The sources of TFP growth in agriculture can be understood through TFP decomposition analysis following the multiple regression frameworks using pooled cross-section time series data with correction for serial correlation and heteroskedasticity (Kmenta, 1981). The TFP can be affected by factors such as research, extension, human resources, intensity of cultivation, balanced application of plant nutrients, infrastructural development and climate. As an input to public investment decisions, it is useful to understand the relative importance of these productivity-enhancing factors in determining productivity growth (Chand *et al.,* 2011).

Following variables were used in the study to identify the source of growth of TFP.

Research stock per ha of crop area = RES_STOK
Extension stock per = EXT_STOK
Proportion of rural population which is literate= LIT_R
Ratio of N to P_2O_5 nutrients used= NPRATIO
Cropping intensity (per cent)= CI
Irrigated area under crop= IRR_IR
Road density (km per 100 sq km)= ROAD
Rail density (km per 100 sq km)= RAIL
Electricity consumption per ha of crop area= ELECT_AG
State/region dummy= DUMMY

Regression analysis was carried out using the above variables and by clubbing together the variables related to natural resources and infrastructure. Three variables representing natural agricultural resources were clubbed together by taking their average as:

1/3 CI +1/3 NPRATIO + 1/3 IRR_CR

Similarly, infrastructural index (INF) was computed from infrastructural variables as:

0.6 ROAD + 0.1 RAIL+ 0.3 ELECT_AG)

[the weights 0.6, 0.3 and 0.1 were based on the experts judgement].

The following two model, as used by Chand *et al.* (2011) in their study. TFP were employed in present study also:

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_CR, ROAD, ELECT_AG, DUMMY)

In Model 1, NARI and INF indices were used to estimate the effect of various factors on TFP. All major individual variables representing natural resources and infrastructure were incorporated in Model 2.

Returns to Research Investments

Using the elasticity of TFP with respect to research stock (RES_STOK), estimated value of marginal product (EVMP) of research stock was obtained as:

EVMP (RES_STOK) = br * (V/ RES_STOK)

where, RES_STOK is the research stock, V is the value of production associated with TFPI and br is the TFP elasticity of research stock estimated in the equation on TFP determinants . The benefit stream was generated under the assumption that the benefit of investment made in research in period t-i will start generating benefit after a lag of five years, at an increasing rate the next nine years, will remain constant during the next nine years and, thereafter start declining. Using timing weights estimated by Evenson and Pray (1991), an investment of one rupee in year t-i will generate a benefit equal to 0.1 *EVMP in the year t-i+6, 0.2*EVMP in the year t-i+7,.... and so on, and it will be 0.9* EVMP in the year t-i+14. After this, the benefit will be equal to EVMP up to the year t-i+23. Then, the benefit from the year t-i+24 onwards will start declining and will be equal to 0.9*EVMP in the year t-i+24, and 0.8* EVMP in the year t-i+25, and so on. This benefit stream can then be discounted at the rate of say 'r', at which the present value of the benefit is equal to one. Thus 'r' is considered as the marginal internal rate of return to public research investment (Mittal and Kumar, 2005).

RESULTS AND DISCUSSION

The results related to TFP in South Gujarat, followed by estimates of returns to investments in agricultural research and its contribution to attaining of self-sufficiency in the selected crops. The TFP estimates pertain to a period of past twenty-four years, starting from 1986-87 to 2009-10. This period has been further divided into two sub-periods, viz. 1986-87 to 1997-98 and 1998-99 to 2009-10.

Measurement of Total Factor Productivity

The TFP indices were calculated across the districts of South Gujarat. This perspective is significant in identifying the region, which shown clear signs of unsustainability in crop production. The input, output and TFP indices were computed for the South Gujarat employing the Divisia-Tornqvist index. Using these indices, the annual compound growth rate of input, output and TFP for the major crops were computed and are presented in Table 4.

Input growth

In South Gujarat, the annual growth in input-use increased slightly during 1986-2009 for all crops except gram. The results for sub-periods have shown higher growth during first period (1986-1997) compared to second period (1998-2009). For the overall period, the Input growth was highest in cotton (0.55 per cent), followed by paddy (0.51 per cent), wheat (0.33 per cent), sorghum (0.27 per cent), banana (0.23 per cent), sugarcane (0.05 per cent) and Tur (0.01 per cent). In the case of gram, input-use in South Gujarat declined by 0.45 per cent while, its output growth increased. Such changes lead to a positive growth in TFP due to shift in area under crops or inward movement of production function (Chand *et al.,* 2011).The share of TFP growth in output growth in such cases have not been reported in the study.

Output growth

Due to the technological changes, the output growth has annually risen by 4.00 per cent in cotton, followed by 2.39 per cent in wheat , 1.84 per cent in tur , 1.74 per cent in paddy, 1.71 per cent in banana, 1.70 per cent in sorghum and 1.19 per cent in gram. The result across sub-periods have shown a declining trend in output growth in paddy, wheat, sorghum, tur, cotton and banana while sugarcane has revealed an increasing trend in output growth.

TFP growth

The productivity performance, measured by the growth in TFP, has shown a considerable variation across crops. Cotton and wheat have enjoyed the maximum

Table 4: Annual growth rates in input use, output and TFP growth in South Gujarat: 1986-87 to 2009-10

(Per cent)

Period	Input growth	Output growth	TFP growth
Paddy			
1986-97	1.20	6.76	**5.56**
1998-09	0.01	0.02	**0.01**
1986-2009 (Overall)	0.51	1.74	**1.23**
Wheat			
1986-97	0.80	5.89	**5.09**
1998-09	0.23	3.12	**2.89**
1986-2009 (Overall)	0.33	2.39	**2.06**
Sorghum			
1986-97	-0.55	3.00	**3.56**
1998-09	0.44	1.53	1.08
1986-2009 (Overall)	0.27	1.70	**1.42**
Gram			
1986-97	-0.13	0.56	**0.69**
1998-09	-1.29	3.03	**4.32**
1986-2009 (Overall)	-0.45	1.19	**1.64**
Tur			
1986-97	0.37	4.09	**3.72**
1998-09	0.07	3.76	**3.69**
1986-2009 (Overall)	0.01	1.84	**1.83**
Cotton			
1986-97	1.99	9.59	**7.60**
1998-09	0.02	3.66	**3.64**
1986-2009 (Overall)	0.55	4.00	**3.45**
Sugarcane			
1986-97	0.09	1.59	**1.50**
1998-09	0.04	2.97	**2.92**
1986-2009(Overall)	0.05	1.11	**1.05**
Banana			
1986-97	0.23	4.28	**4.05**
1998-09	0.29	3.02	**2.73**
1986-2009 (Overall)	0.23	1.71	**1.49**

benefit of technological innovations throughout the period of past twenty four-years with the TFP growth of over 2 per cent.

The study of TFP growth by crops in South Gujarat developed a strong perception that technological gain had occurred in paddy, wheat, tur, cotton, sugarcane and banana. For the overall period 1986-2009, the TFP showed a positive and significant growth in all the selected crops, it being highest in cotton (3.45 per cent) followed by wheat (2.06 per cent), tur (1.83 per cent) , banana (1.49 per cent) , sorghum (1.42 per cent), paddy (1.23 per cent) and sugarcane (1.05 per cent).

Share of TFP Growth

The TFP captures the extent of increase in total output which is not accounted for by the increases in total inputs. The TFP index measures the growth in net output per unit of factor input. In the production function framework, TFP growth indicates technological progress which represents shifts in the production function over time (Ranjitha and Mruthyunjaya, 2008).

Using the estimates of TFP growth, its share in output growth was estimated for the selected crops of South Gujarat in the two sub-periods and for the total period, 1986-87 to 2009-10 (Table 5). These estimates were computed only for those cases in which TFP growth was positive. For the crops depicting higher growth of TFP, the output growth was largely attributed to technology. Under such a situation, the share of TFP growth in output growth would reflect a higher share in comparison to those crops where the technology induces a higher use of inputs. During the past two decades, the share of TFP growth in output growth was estimated to be between 70 per cent and 99 per cent for selected crops - the lowest being for paddy and the highest for tur. About 70 per cent increase in paddy output and 84 per cent to 99 per cent increase in the output of wheat, sorghum, tur, cotton, sugarcane and banana could be possible through technological change. Sub-period-wise data have shown that contribution of technology to output growth was higher during Period-II (1998-2009) than during Period-I (1986-1997) for all the selected crops, except banana.

Table 5: Share of TFP growth in output growth of selected crop in South Gujarat: 1986-87 to 2009-10

(Per cent)

Crop	TFPG share in output growth		
	1986-1997	1998-2009	1986-2009
Paddy	82.25	50.00	70.69
Wheat	86.42	92.63	86.19
Tur	90.95	98.14	99.46
Cotton	79.25	99.45	86.25
Sugarcane	94.34	98.32	94.59
Banana	94.63	90.40	87.13

The growth in TFP has been attributed largely due to investment in agricultural research that provided high payoffs. These results corroborated with those of Mruthyunjaya and Ranjitha (1998) and Evenson *et al.* (1999).

Prioritization of Research Resource Allocation

To address the issues of technological progress and crop sustainability in South Gujarat, the selected crops were classified into five groups according to the magnitude of growth in TFP, as under (Chand *et al*., 2011):

Negative growth: TFP growth less than zero

Stagnant growth: TFP growth positive but less than 0.5per cent

Low growth: TFP growth of 0.5-1per cent

Moderate growth: TFP growth of >1.0-2.0per cent

High growth: TFP growth of more than 2per cent

The distribution of selected crops of South Gujarat in different TFP growth categories is depicted in Table 6. A perusal of table 6 reveals that cotton and wheat have witnessed a high growth in TFP (more than 2per cent). Similarly, paddy, sorghum, tur, sugarcane, banana and gram have experienced a moderate growth (> 1.0 – 2.0 per cent) in TFP.

The results relating to TFP growth indicate that much technological gains have been experienced in all the selected crops of South Gujarat as shown by moderate to high growth in the total factor productivity.

Sources of Total Factor Productivity

The growth rate in TFP was also analysed in terms of contribution of different factors to TFP growth. The estimated effect of various factors which included research stock, extension stock, natural resource management, infrastructure, literacy level, etc. on TFP for selected crops under study has been presented in Table 7. The results reveal that the public investment in research constituted a significant source of TFP growth in all the crops.

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. TFP elasticity with respect to research stock ranged from 0.018 for banana to 0.056 for sugarcane (Table 8). 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 be to increase by 37 per cent for rice, 19 per cent for wheat, 28 per cent for tur, 18 per cent for sugarcane , 30 per cent for cotton and 55 per cent for banana per annum. On an average, the investments on research in agriculture need to an increase of about 31 per cent per annum to achieve one per cent growth in TFP.

Returns to Investment on Agricultural Research

Value of Marginal Product

The estimated value of marginal product (EVMP) of research investment is given in Table 9. The results revealed that additional investment of one rupee in research generated, on an average, additional income of ₹7, indicating very high rates of returns to public investments. Highest marginal product of research was achieved in sugarcane and wheat where additional investment of ₹ 1 generated additional output worth ₹

Table 7: Direction of sources of TFP growth for selected crops in South Gujarat: 1986-87 to 2009-10

Crops	Model 1	Model 2
Paddy	Research (+)	Research (+)
	INF (+)	N:P2O5 ratio (+)
	NARI (+)	Road (+)
Wheat	Research (+)	Research (+)
	NARI (+)	Cropping Intensity(+)
		Road (+)
		Irrigation(+)
Sorghum	Research (+)	Research (+)
	Literacy (-)	Literacy (-)
	NARI (+)	Road (+)
Tur	Research (+)	Research (+)
	INF (+)	Irrigation (+)
		Road(+)
Cotton	Research (+)	Research (+)
	INF (+)	Literacy (+)
	NARI (+)	N:P2O5 ratio (+)
		Road (+)
Sugarcane	Research (+)	Research (+)
	INF (+)	Road (+)
	NARI (+)	Irrigation (+)
Banana	NARI (-)	Electricity (-)
	Literacy (+)	Literacy (+)
	Research (+)	Road (+)

Table 8: Elasticity of TFP with respect to research stock for major crops in South Gujarat

Crop	TFP elasticity with respect to research stock			Research stock
	Model 1	Model 2	Average	
Paddy	0.025	0.028	0.027	37.46
Wheat	0.081	0.027	0.054	18.56
Tur	0.042	0.030	0.036	27.88
Sugarcane	0.062	0.050	0.056	17.82
Cotton	0.028	0.038	0.033	30.49
Banana	0.014	0.022	0.018	55.07

Table 6: Trends in total factor productivity growths in selected crops of South Gujarat: 1986-87 to-2009-10

Particulars	Total factor productivity growth category			
	< 0.5 per cent (Stagnant growth)	**0.5-1 per cent (Low growth)**	**>1-2 per cent (Moderate growth)**	**>2 per cent (High growth)**
Positive	-	-	Paddy, sorghum, tur, sugarcane, banana and gram	Wheat and cotton
Negative	-	-	-	-

Table 9: Estimated value of marginal product of research stock in different crops of South Gujarat: 1986-87 to 2009-10

(₹)

Crop	1986-1997	1998-2009	1986-2009
Paddy	4.87	3.09	4.24
Wheat	10.23	11.19	10.35
Tur	7.15	6.85	7.18
Cotton	5.73	6.39	5.73
Sugarcane	11.54	10.67	10.62
Banana	3.73	3.17	3.16

10.62 and ₹ 10.35, respectively. Returns to research investment of additional one rupee were ₹ 4.24 in paddy, ₹5.73 in cotton, ₹ 7.18 in tur and ₹ 3.16 in banana during the period 1986-2009.

The value of marginal product more than "1" indicates that research in that commodity has been generating enough output to justify investment. There is a need to change the focus of research in such crops where marginal rate of return was less compared to other crops to get higher returns from research investments. Research investment is a significant determinant in growth of TFP for all selected crops. The results also corroborated with the findings of Rosegrant and Evenson (1995), Evenson *et al*. (1999), Thorat *et al.* (2006) and Chand *et al.* (2011).

Internal Rate of Return

Research is an important contributor to productivity enhancement. Table 10, which shows the impact of research in different crops, indicates high payoffs to research in all crops. The internal rates of return (IRR) to research investment for selected crops were estimated and are given in Table 10. The marginal internal rates of return (MIRR) to agricultural research were found between 35 per cent and 54 per cent showing that investment on research in agriculture during the past 24 years has provided attractive returns. A value of MIRR as 45 per cent means that every rupee invested in research has yielded a return of 45 per cent annually. Such a high rate of return not only justifies these investments but is also an indicator of underinvestment in agricultural research. During the period 1986-2009, the overall internal rates of return to public agricultural research investment turned out to be 38 per cent for rice, 51 per cent for wheat, 47 per cent for tur, 43 per cent for cotton, 54 per cent for sugarcane and 35 per cent for banana. These results suggest that further investments on research in agriculture will generate significant returns and lead to development of agriculture not only in South Gujarat but also the state as a whole.

Table 10: Estimated marginal internal rate of return to research investment in different crops in South Gujarat: 1986-87 to-2009-10

(Per cent)

Crop	1986-1997	1998-2009	1986-2009
Rice	41	32	38
Wheat	53	52	51
Tur	47	46	47
Cotton	43	45	43
Sugarcane	55	54	54
Banana	37	35	35

Contribution of Agricultural Research to Crop Output: Quantity and Value

The share of TFP growth in output growth has been estimated in the range of 70 per cent for paddy to 99 per cent for tur (vide Table 5). The share of agricultural research in TFP growth has been estimated as 30.32 per cent for paddy, 18.10 per cent for wheat, 20.38 per cent for tur, 10.81 percent for cotton, 35.52 per cent for sugarcane, 25.03 per cent for banana (Table 11). These two sets of numbers in shares were multiplied to arrive at the contribution of research to production growth. Based on these estimates it was found that around thirty-three percent growth in output of sugarcane, one-fifth in the case of paddy, tur, and banana, 15.6 per cent in the case of wheat and 9.3 per cent in cotton were due to investments on research in agriculture. In most of the crops, about one-fifth of output growth was achieved due to public investment on research in agriculture.

The estimates presented in this study provide 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 crops of South Gujarat during the year 2009-10 has been presented in Table 11 as an illustration. The growth rate in production of a given crop was used for the period 1986-87 to 2009-10 for assessing the contribution of research to agricultural production. During this period, the output of banana increased by 9.43 per cent each year in which 2.06 percentage point growth was due to research. The output in paddy increased by 3.96 per cent each year in which 0.85 percentage point growth was due to research in agriculture. This implies that 0.85 percentage growth in paddy output during 2009-10 was due to research which amounts to 0.0044 Mt in terms of additional quantity. Valued even at the farm harvest price, this incremental output is worth ₹4.05 crore. As mentioned under the Methodology Section, this contribution does not include the research contribution in improving the quality which fetches premium price like fine grain or improved varieties. Similarly, the contribution of research in wheat crop during 2009-10 has been estimated to be 0.0005 Mt; it is valued at ₹0.54 crore. Cotton crop ranked second after banana in terms of contribution of research; it is valued at ₹6.19 crore. Sugarcane fetched ₹5.11 crore from the contribution of research investment and it ranked third in selected crops of South Gujarat.

The total contribution of agricultural research in the value of output of the 6 selected crops has been computed as ₹49.23 crore (Table 12). These six crops accounted for

Table 11: Contribution of agricultural research investment to major crops in South Gujarat: 2009-10

Particulars	Paddy	Wheat	Tur	Cotton	Sugarcane	Banana
Share of TFP in output growth (per cent)	70.69	86.19	99.46	86.25	94.59	87.13
Share of research in TFP growth (per cent)	30.32	18.10	20.38	10.81	35.52	25.03
Share of research in output growth (per cent)	21.43	15.60	20.27	9.32	33.60	21.81
Crop production growth (per cent)	3.96	4.18	0.34	8.72	4.65	9.43
Contribution of research in production growth (percentage points)	0.85	0.65	0.07	0.81	1.56	2.06
Production in 2009-10 (million tonnes)	0.514	0.074	0.100	0.331	1.212	2.107
Contribution of research to production (million tonnes)	0.0044	0.0005	0.0001	0.0027	0.0189	0.0433
Price: 2009-10 (₹/q)	928	1125	2705	2301	270	765
Contribution of research to selected crops (in crore ₹)	4.05	0.54	0.19	6.19	5.11	33.15

Table 12: Contribution of research to crop sector in South Gujarat: 2009-10

Particulars	Value
Contribution of research to selected 6 crops (in crore ₹)	49.23
Share of the selected crops under study in value of output (per cent)	66.63
Research contribution to total crop sector based on selected crops (in crore ₹)	73.89
Research investment in the year 2009-10 (in crore ₹)	55.09
Returns to research investment (per cent)	34.12

about 67 per cent of the value of crop output in 2009-10. If the crops not included in the study could also experience a similar growth in TFP and could have the same contribution of research to TFP growth as is the average of these six crops, then the contribution of research to South Gujarat agriculture comes to be ₹ 73.89 crore for the crop sector (Table 12). This contribution is 34 per cent higher than the annual investment crop sector research by the public sector. It is thus clear from the study that investment in agricultural research is highly paying proposition and presents a strong case for additional allocation of research resources for the development of agriculture in South Gujarat.

CONCLUSIONS

Agricultural output is largely determined by the inputs used in production and the efficiency or productivity with which these inputs are used. To evaluate the performance of any production system the Total Factor Productivity (TFP) is a key concept. It depicts the acceleration of output growth and extent of sustainability of the system. It also indicates the role of technology in increasing resource-use efficiency and thus widening the carrying capacity of a system.

The study has revealed significant regional variations in the TFP growth of major crops of South Gujarat. Research, extension, cropping intensity, rural electrification, irrigation, NP ratio and road density have been observed to be the most important instruments of growth in TFP. The results of the study have important policy implications for the allocation of scarce public resources to research, extension, infrastructural development and natural resources management. It will help to achieve low-cost production growth, food security and poverty alleviation.

Increases in productivity, measured by the growth in TFP have shown considerable variations across crops. Cotton has enjoyed the highest benefit of technological innovations during the past 24 years (1986-87 to 2009-10) with its TFP growth close to 1.05 - 3.5 per cent. Rice lags far behind wheat, while sorghum has witnessed annual TFP growth of around 1.42 per cent. Most of the crops have experienced a lower growth in TFP after the first period, viz. 1986-87 to 1997-98. This might be due to non-sustainability of level of yield in the long-run in most of the crops. In pulse crops, tur and gram have witnessed a positive growth in TFP indicating that these crops have benefited from the technological gains. The TFP growth for sugarcane has remained close to 1 per cent.

Banana is amongst the major crops of South Gujarat. It has depicted a high positive growth in TFP (1.49 per cent). However, the growth in TFP declined substantially after the first period, 1986-87 to 1997-98. Since the overall growth in output of banana has been driven by technological innovations and use of inputs, its economic viability sustained for a long period.

The study on returns to investment on agricultural research has revealed that investment in agricultural R&D is a highly paying proposition. An additional investment of ₹1 on research stock has generated, on an average, an additional income of ₹4.24 to ₹10.62 in different crops, indicating high rates of returns to public investments. The value of marginal product more than "1" indicates that research on that commodity has been generating enough output to justify investment on R&D. However, there is a need to change the focus of research in such crops where marginal rate of return has been less so as to get higher returns from research investments.

Research investment has been a significant determinant of TFP growth in all the selected crops of South Gujarat. The marginal internal rates of return to agricultural research have been estimated to be between 35 per cent (in banana) and 54 per cent (in sugarcane). Returns to research for all selected crops have increased over time. Therefore, investment in agricultural research has made a significant contribution to the state economy.

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