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TOTAL FACTOR PRODUCTIVITY AND SOURCES OF LONG-TERM GROWTH IN INDIAN AGRICULTURE

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ABSTRACT

This paper assesses total factor productivity (TFP) growth in India, examines the sources of productivity growth, including public and private investment, and estimates the rates of return to public investments in agriculture. The results show that significant TFP growth in the Indian crops sector was produced by investments -- primarily in research -- but also in extension, markets, and irrigation. The high rates of return, particularly to public agricultural research and extension, indicate that the Government of India is not over investing in agricultural research and investment, but rather that current levels of public investment could be profitably expanded.

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TOTAL FACTOR PRODUCTIVITY GROWTH AND SOURCES OF LONG-TERM GROWTH IN INDIA[*]

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1. INTRODUCTION

Productivity growth is of central importance both to economic growth and to the role of government policy in promoting growth. Increases in productivity can be induced by public investments in research, extension, human capital development, and infrastructure. As an input into public investment decisions, it is critical to understand the relative importance and rates of return to these productivity-enhancing investments.

India has undertaken particularly large public investments in research, extension, and irrigation. However, in India, as elsewhere in the developing world, concern is increasing over whether incremental investments in public research and extension still generate high returns. The magnitude of returns to public investment is particularly

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important for India during a period of policy reforms to liberalize the economy. This period of economic transition is accompanied by budget constraints which motivate careful rationing of public investment funds, raising the question of whether India needs continuing large public expenditures for agriculture. These concerns are heightened by a perception that the returns to agricultural research and irrigation may be declining over time because the "easiest" gains from the green revolution have already been reaped through rapid spread of modern varieties of wheat and rice, leading to high levels of attainment of modern variety adoption and high levels of input use in many regions of India; because of the failure of domestic and foreign research to generate crop varieties with higher maximum yields than varieties produced in the 1960s; and because of the increasing capital costs of irrigation, as the best sites have been utilized. Economic liberalization also heightens the importance of private sector activities in promoting productivity growth. It is therefore important to understand the magnitude of social benefits of private investment.

To address these issues, this paper assesses total factor productivity (TFP) growth in India, examines the sources of productivity growth, including public and private investment, and estimates the rates of return to public investments in agriculture. Are the returns to agricultural research in India still high? Are returns to research 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 private research on productivity growth?

In the rest of the paper, we first describe the methodology for estimation of TFP, decomposition of TFP, and estimation of rates of return to public investments, then describe the data, and present results and policy implications.

2. METHODOLOGY AND DATA

ESTIMATION OF TOTAL FACTOR PRODUCTIVITY

Analysis of total factor productivity measures the increase in total output which is not accounted for by 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 analysis, Tornqvist-Theil TFP indices are computed for 271 districts covering 13 states in India, 1956-87.

Expressed in logarithmic form, the Tornqvist-Theil TFP index is

$$\ell n(TFP_t / TFP_{t-1}) = \text{‰} \sum_j (R_{jt} + R_{jt-1})\, \ell n\,(Q_{jt} / Q_{jt-1}) - \text{‰} \sum_j (S_{it} + S_{it-1})\, \ell n\,(X_{it} / X_{it-1})$$

where R_{jt} is the share of output j in revenues, Q_{jt} is output j, S_{it} is the share of input i in total input cost, and X_{it} is input i, all in period t. Specifying the index to equal 100 in a particular year and accumulating the measure based on equation (1) provides the TFP index.

The Tornqvist-Theil index is a superlative index which is exact for the linear homogeneous translog production function (Diewert). A further advantage of the

Tornqvist-Theil index is that it accounts for changes in quality of inputs. Because current factor prices are used in constructing the weights, quality improvements in inputs are incorporated, to the extent that these are reflected in higher wage and rental rates (Capalbo and Vo).

The Tornqvist-Theil index provides consistent aggregation of inputs and outputs under the assumptions of competitive behavior, constant returns to scale, Hicks-neutral technical change, and input-output separability. However, Caves, Christensen and Diewert have shown that Tornqvist-Theil indices are also superlative under very general production structures, i.e., nonhomogeneous and nonconstant returns to scale, so they should provide consistent aggregation across a range of production structures (Antle and Capalbo).

Five major crops (rice, wheat, sorghum, pearl millet, and maize) and fourteen minor crops (barley, cotton, groundnut, other grain, other pulses, potato, rapeseed, mustard, sesame, sugar, tobacco, soybeans, jute, and sunflower) are included in the output index. Farm prices are used to aggregate the outputs. Inputs included in the input index are irrigated land, unirrigated land, tubewell irrigation capital, human labor, animal labor, tractors, and fertilizer. Inputs are aggregated using farm rental prices, with differentiation of rental prices for irrigated and unirrigated land. The value of publicly funded surface irrigation as an input is therefore approximated by its effect on land prices. The capital value of tubewell irrigation is directly incorporated in the input index through the rental price on tubewell investment.

TOTAL FACTOR PRODUCTIVITY DECOMPOSITION

Increases in productivity can be induced by investments in research, extension, human capital, and infrastructure. As an input into public investment decisions, it is useful to understand the relative importance of these productivity-enhancing investments in determining productivity growth. The second part of the analysis is therefore to estimate the sources of growth of TFP and, based on these estimates, to compute the relative contribution of growth and marginal rate of return to productivity-enhancing investments.

In order to assess the determinants of TFP, the TFP index was estimated as a function of variables representing investments in public and private research, extension, human capital, and infrastructure. Estimation was undertaken using a fixed effects approach for the pooled cross section time series district level data set, with corrections for serial correlation and heteroskedasticity (Kmenta). The total number of observations in the data set is 8,672. Because we are interested in changes in the impact of investments over time, three separate decomposition equations are estimated, for the period 1956-66, roughly corresponding to the pre-green revolution period; 1967-77, representing the green revolution period; and 1978-87, representing the post-green revolution period.

TFP decomposition specifications essentially relate TFP growth to changes in technology, infrastructure, and skills by developing variables that measure the *flows* of new technology, infrastructure services, and skill changes. For technology, this requires that variables based on past research and extension programs be developed. In general, there are no strong functional form implications to be derived from optimization theory that can be imposed on this specification unless there is reason to believe that governments actually choose TFP growth-producing projects in an optimizing fashion. For variables such as research and extension, the variable definitions must reflect the possible long lags in impact of an expenditure in a given time period. The appropriate research variable should, therefore, reflect a cumulation in its timing weights. In addition, it should reflect technological spill-in from outside the district.

The general form for the research variable is:

$$R^*_{ik} = \sum_j G_{ij} \sum_k W_{ik}\, r_{ijt\text{-}k}$$

where $r_{ijt\text{-}k}$ is research investment in commodity i, region j, in period t-k. The research stock is thus based on cumulated past investments and weighted by two sets of weights. The first set, G_{ij}, are spill-in weights measuring the degree to which research conducted in location j is productive in location i relative to the productivity of research conducted in location i. These weights are based on geo-climate regions. The second set of weights are time-shape weights, W_{ik}. These weights reflect both the lag between research expenditure and the ultimate productivity impact and the real depreciation of research impacts. A lag process of 27 years was estimated for research. For extension, a three-year average lag was assumed, but not directly estimated.

There is also an aggregation issue that must be dealt with in cases where research variables must be aggregated across commodities (i.e., over i). For cases where the dependent variable is cumulated TFP, each commodity research variable could be included as a regressor. However, this often results in a high degree of multicollinearity, so aggregation is desirable. Here we sum the value of research investment across commodities to derive total research investment for all commodities.

The independent variables utilized in the analysis for India include the following: MKTS, the number of regulated markets, as a proxy for rural infrastructure development; NIANCA, the ratio of net irrigated area to net cropped area; RELWAGE, the ratio of farm wages to annual earnings of non-farm workers; LITERACY, the proportion of rural males who are literate; EXT, lagged extension expenditures per farm; RES, the stock of research, computed as a weighted distributed lag of research expenditures as described above; WHYV, the proportion of area under modern crop varieties, weighted by crop shares; YEARRAIN, JUNERAIN, and JUAURAIN, which are annual, June, and July/August rainfall, the latter two measures representing important monsoon periods; YEAR, which is a linear trend variable; MCOST, the ratio of wholesale price to farm price; and DOMINV and FORINV, the sum, respectively, of cumulated domestic and foreign patented inventions of agricultural implements, weighted by tractor share in inputs, plus cumulated inventions for fertilizer, seed, and chemicals, weighted by the fertilizer share in inputs. Finally, dummy variables are included for agroclimatic zone. Table 1 summarizes the variables used in the analysis.

TFP GROWTH ACCOUNTING AND MARGINAL RATES OF RETURN TO INVESTMENT

The relative impact on TFP of the investment and other variables can be shown more readily by undertaking a growth accounting exercise, which relates actual productivity growth to changes in the relevant productivity-enhancing variables. The growth accounting exercise utilizes the estimated parameters for the sources of growth in the TFP decomposition equations, combined with the rate of growth in the sources of growth, to estimate the contribution of each of these sources to TFP growth.

Finally, marginal internal rates of return to public investment in research and extension are computed from the estimated TFP decomposition equation. To compute marginal rates of return, the stream of marginal output generated from the investments was first computed utilizing the estimated parameters from the TFP decomposition equations and the lag structure of the public research and extension variables. Then the marginal internal rates of return were computed as the discount rate at which this stream of output has a unit value.

Table 1--Summary of variables: TFP decomposition analysis

	Definition	Mean
Dependent Variable		
TFP	Total Factor Productivity Index	1.15
Independent Variables		
Technology Variables		
EXT	Agricultural Extension Staff per 1000 Farms	4.78
RES	Agricultural Research Stocks (Billion Rupee)	25.72
WHYV	Proportion of Crop Area in Modern Varieties	0.16
DOMINV	Factor-Weighted Domestic Invention Stock (no.)	0.96
FORINV	Factor-Weighted Foreign Invention Stock (no.)	90.88
Infrastructure-Institutional Variables		
MKTS	Number of Regulated Markets	9.87
NIANCA	Net Irrigated Area/Net Cultivated Area	0.25
RELWAGE	Daily Farm Wage/Annual Non-Farm Earnings	0.0012
LITERACY	Proportion of Rural Adult Males Literate	0.32
MCOST	Crop Wholesale Price/Crop Farm Price, 1956	1.23
Other Variables		
YEAR	Year	--
AGRO1-AGRO8	Agro-Climate Dummy Variables	--
YEARRAIN	Annual Rainfall (mm)	1040.60
JUNERAIN	June Rainfall (mm)	137.05
JUAURAIN	July-August Rainfall (mm)	535.81

3. RESULTS

TOTAL FACTOR PRODUCTIVITY GROWTH

Trends in total factor productivity in India are shown in Figure 1 and Table 2. TFP grew relatively steadily over time, with modest variation in growth rate over periods, but with large fluctuations due to weather variation. Particularly large drops in TFP occurred in the severe drought years of 1965, 1966, and 1979. Variation in TFP around trend is due nearly entirely to variation in output, as total input use increased smoothly over time. The rate of growth in TFP in the Indian crops sector,

1956-87, was 1.13 percent per annum, or about two-thirds of the rate of growth in TFP in U. S. postwar agriculture (Jorgenson and Gollop). With total output growth increasing at 2.25 percent per annum, productivity growth has accounted for just over one-half of total output growth in the Indian crops sector. Table 2 shows that the most rapid growth in input use, output, and TFP was during the green revolution period.

TOTAL FACTOR PRODUCTIVITY DECOMPOSITION

The estimated parameters from the TFP decomposition equations for the crops sector for each of the periods are presented in Tables 3-5. Estimated of brevity. The results indicate that public research, extension expenditures, irrigation, and foreign private research each have a statistically significant, positive impact on TFP through all periods.

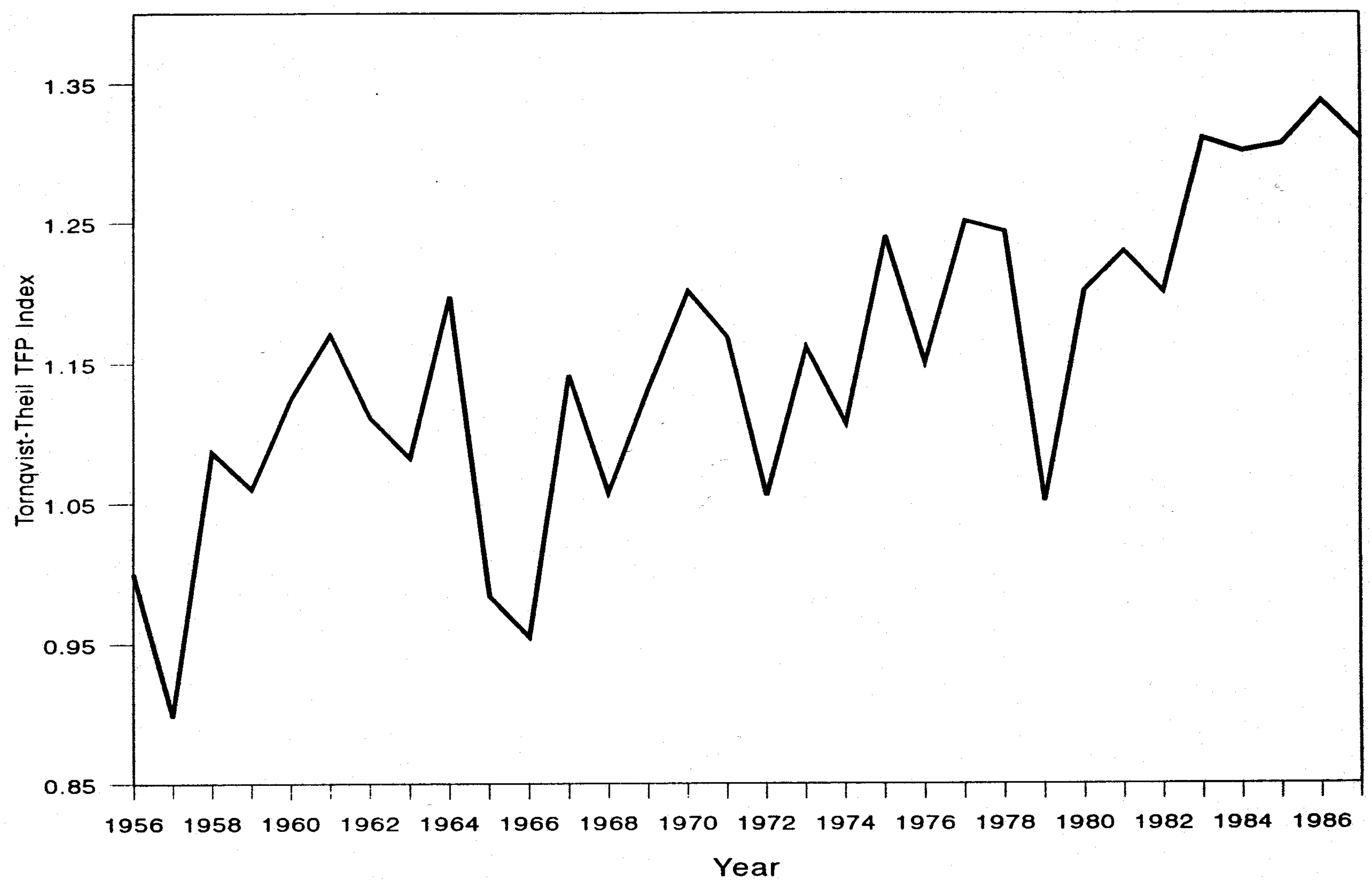

Figure 1. Total Factor Productivity in the Indian Crop Sector, 1956-87

Table 2--Annual growth rates in crop output, inputs, and total factor productivity, in percent, based on three-year moving average.

	Period			
Items	1957-67	1967-76	1976-86	1957-86
Crop output	2.18	2.68	2.07	2.25
Crop input	1.08	1.28	1.00	1.11
Total factor productivity	1.10	1.39	1.05	1.13

Table 3--Total factor productivity decomposition for the crops sector, India, 1956-66, estimated parameter.

Variables	Parameter Estimates	T-Ratio
INTERCEPT	-0.352**	-4.84
MKTS	0.025**	6.09
NIANCA	0.141**	5.23
RELWAGE	-0.029**	-3.05
LITERACY	-0.243**	-3.63
EXT	0.063**	8.88
RES	0.066**	10.36
YEARRAIN	0.013**	10.36
JUNERAIN	-0.002	-0.49
JUAURAIN	-0.004*	-2.01
YEAR	-0.026**	-11.13
MCOST	-0.001	-0.03
DOMINV	0.004*	1.94
FORINV	0.033**	6.27

R^2 between observed and predicted = 0.27

F-ratio = 83.51   Degrees of freedom = 2,960

Note: Asterisks indicate significance levels: **=1%, *=5%.

Dependent variable is the log of the TFP index. All variables specified in logarithms, except those variables defined in percentage terms, which enter linearly (LITERACY, WHYV).

Table 4--Total factor productivity decomposition for the crops sector, India, 1967-77, estimated parameters

Variables	Parameter Estimates	T-Ratio
INTERCEPT	-0.126*	-2.09
MKTS	0.001	0.20
NIANCA	0.177**	9.06
RELWAGE	-0.016*	-1.97
LITERACY	-0.083	-1.54
EXT	0.059**	9.20
RES	0.053**	9.71
WHYV	0.090**	4.78
YEARRAIN	0.011**	10.07
JUNERAIN	-0.001	-0.34
JUAURAIN	-0.008**	-5.41
YEAR	-0.010**	-8.53
MCOST	-0.075**	-3.64
DOMINV	0.022**	6.11
FORINV	0.015**	2.59

R^2 between observed and predicted = 0.30

F-ratio = 93.45 Degrees of freedom = 2,960

Note: Asterisks indicate significance levels: **=1%, *=5%.

Dependent variable is the log of the TFP index. All variables specified in logarithms, except those variables defined in percentage terms, which enter linearly (LITERACY, WHYV).

Table 5--Total factor productivity decomposition for the crops sector, India, 1978-87, estimated parameters

Variables	Parameter Estimates	T-Ratio
INTERCEPT	-0.475**	-5.22
MKTS	0.027**	4.75
NIANCA	0.240**	12.37
RELWAGE	0.021	1.90
LITERACY	0.179**	3.13
EXT	0.041**	4.33
RES	0.049**	7.74
WHYV	-0.033*	-2.11
YEARRAIN	0.010**	8.55
JUNERAIN	0.006**	2.69
JUAURAIN	0.002	1.15
YEAR	-0.002	-0.78
MCOST	-0.034	-1.59
DOMINV	-0.001	-0.23
FORINV	0.049**	5.99

R^2 between observed and predicted = 0.31

F-ratio = 96.11   Degrees of freedom = 2,710

Note: Asterisks indicate significance levels: **=1%, *=5%.

Dependent variable is the log of the TFP index. All variables specified in logarithms, except those variables defined in percentage terms, which enter linearly (LITERACY, WHYV).

The impact of markets, as a proxy for rural investment, is positive in all periods, and significant in the first and third periods. The impact of relative wages is negative in the first two periods: an increase in non-farm income tightens the labor market in agriculture, which induces increased efficiency in production. The third period results are counterintuitive.

As noted above, irrigation has a direct impact on output through its contribution to input levels. The results show that the proportion of area irrigated has additional effects on productivity not accounted for by its contribution to total input levels. The estimated effect of irrigation on TFP is strongly positive, indicating that irrigation does in fact have an influence on productivity above and beyond its value as an input. The expected positive effects of literacy on TFP do not emerge until the final, post-green revolution period. The high returns to literacy in the post-green revolution period are consistent with the increasing importance of efficiency in input use as opposed to input and crop variety promotion during this period. Technologies to implement post-green revolution technologies tend to be highly complex, knowledge-intensive, and location specific. Because new technologies are more demanding for both the farmer and the extension agent, they require more information and skills for successful adoption compared to the initial adoption of modern varieties and fertilizers. As a result of the greater complexity of post-green revolution technologies, increased investment in education and human capital is likely to have high payoffs.

The variable MCOST is a proxy measure for the initial stage of market and infrastructure development of each district, allowing testing of the convergence hypothesis, which states that those areas which are initially relatively worse-off will tend to catch-up over time; and the urban-industrial hypothesis of Schultz, Nichols, and Tang. This hypothesis essentially states that locations near urban-industrial activity have better markets and lower transaction costs. Since the ratio of wholesale price (at market centers) to farm prices (at the district level) rises with distance from the center, this variable is indexing transaction costs at the beginning of the period.

In convergence studies, the convergence variable measures the initial distance between leader and follower regions and does not address transaction costs. The estimated negative coefficient of MCOST shows that as transaction costs rise, TFP growth is lowered, indicating that convergence does not overcome the limitation effects of poor markets.

The time trends indicate a negative secular decline in TFP, independent of the growth in the TFP-enhancing investments investigated. This result may be a measure of the impact of resource degradation in agriculture. Unfortunately, it has not proven possible to obtain data to consistently measure degradation impacts.

Has the contribution of agricultural research, extension, and irrigation to TFP growth declining over time? The estimated parameters for the research and extension variables in Tables 3-5 show that the marginal impact of these investments have in fact declined, but not by very much. In the third period, the research impact was over three-fourths of that in the first period, while the extension impact was two-thirds that of the initial period. As will be shown below, the economic returns to these investments remained very high in the final period.

The marginal impact on TFP of the expansion in irrigated area (above its value as a direct input) has steadily increased over time. This improvement can be attributed to rapid growth in the proportion of private tubewell (groundwater) irrigation compared to public canal irrigation. Between the late 1950s and the mid 1980s the proportion of irrigated area under private tubewells increased from one-third to over one-half. Micro-level studies confirm that the productivity of privately irrigated area is significantly higher than areas dependent on canal (Dhawan, 1989).

TFP GROWTH ACCOUNTING

The growth accounting exercise further clarifies the relative impact on TFP of the investment and other variables over time. Table 6 reports "explained" TFP growth components by period. A key result of the decomposition analysis is an understanding of the underpinnings of the respectable total factor productivity growth in India during the 1956-66 period, before the rapid spread of modern varieties. This was a period of rapid growth in investment in research and extension and very rapid growth in inventions in agricultural implements and inputs generated by private research and investment. A large part of the explained growth throughout the 1956-87 period is associated with the foreign research and development, as measured by the stock of inventions, but this is particularly true for the pre-green revolution period.

Table 6--Contribution to total factor productivity growth by source of growth, Based on TFP decomposition equation

	1956-66	1967-77	1978-87	1956-87
Markets	.062	.001	.076	.035
Irrigation[a]	.036	.100	.110	.084
Extension	.420	.290	.322	.331
Public Research	.321	.190	.267	.258
HYVs	0	.192	-.002	.070
Domestic Private R+D	.069	.234	.000	.145
Foreign Private R+D	.410	.182	.245	.261
Literacy	-.080	-.023	.064	-.012
Relative Wage	-.008	-.015	-.003	-.009
Year	-.181	-.070	-.012	-.104

[a] Incremental contribution above and beyond the value of irrigation as a direct input.

Previous studies have not attributed growth in India to this process of adoption of privately developed inventions. However, we would note that private inventions were the basis for the post-World War II "modern" boom in developed country agriculture. The United States, for example, achieved unprecedented TFP growth during this period, much of it attributed to private sector R&D (Evenson and Huffman, 1993). And it appears that the "modernization" of Indian agriculture -- with the introduction of improved fertilizers and other modern inputs -- has similarly contributed significantly to TFP growth.

A second observation is that the contribution of HYVs to TFP growth is quite modest. Only during the green revolution period do HYVs contribute significantly to TFP growth. Since the analysis incorporates research and extension variables measuring Indian research activity, we would interpret the HYV contribution as the "imported HYV" contribution. Most of the modern varietal development is the product of Indian research, not of imported varieties. During the post-green revolution period, the impact of research and extension has been mainly through replacement of older generations of HYVs by newer generations with improved traits, rather than through direct expansion of HYVs to new areas.

Over the entire 32 year period, foreign R&D contributed one-fourth of TFP growth, and nearly 40 percent of TFP growth in the pre-green revolution period. Indian private sector R&D was also a major contributor to TFP growth, explaining nearly 15 percent of growth, with the main contribution coming during the green revolution period.

Public sector agricultural research and extension were very important, with the former contributing one-fourth of TFP over all three periods, and the latter one-third of TFP growth over the three periods. Thus, over the full period, public agricultural research and extension together accounted for well over one-half of TFP growth. Modern varieties accounted for only seven percent of TFP growth, and markets (as a proxy for rural infrastructure) and irrigation infrastructure together contributed approximately ten percent of TFP growth over the full period, with a contribution of nearly 18 percent in the post-green revolution period. Note that the latter measures only the incremental impact of irrigation above its contribution as a conventional input.

These estimations are not intended to be exact representations of the contributions to growth. The markets and irrigation investments are probably picking up some of the contributions of other infrastructure investments. The mechanisms by which the foreign R&D contribution generates growth is not easily characterized. This variable is weighted by modern input factor shares and its contribution is therefore related to growth in these shares -- hence to the "modernization" of Indian agriculture.

These questions of interpretation, however, do not prevent us from drawing general conclusions regarding TFP growth in Indian agriculture. India has realized significant and important rates of TFP growth across all periods examined. Most of this TFP growth can be linked to investments made in research, extension, markets, and irrigation. Imported investments (foreign R&D and HYVs) have played an important role in TFP growth. While we have not been able to pose questions related to broader policy impacts on TFP growth, we do conclude that the statistical quality of the estimates and their consistency with Indian experience justify the investment analysis presented in the next section.

RATES OF RETURN TO PUBLIC INVESTMENTS

We conclude our analysis of sources of growth by analyzing the economic returns to growth-producing investments. Economic rates of return to investment can be computed from the estimated parameters of the TFP decomposition analysis presented

Tables 3-5. Note that the investment perspective differs from the growth accounting perspective in an important respect. For the investment perspective we attempt to measure the benefit stream associated with an increment to investment in research, extension, and irrigation. The growth accounting perspective instead takes into account the growth in investment in these activities and measures the associated TFP growth.

In interpreting the results, it is important to first note that the HYV, private R&D, and irrigation estimates are only part of the full marginal products of these investments. For public extension and research investments, we can consider these to be the full social products. For HYVs, as noted in our discussion, these are predominantly imported -- particularly from IRRI and CIMMYT. Many of these HYVs have been widely planted or used as parent stock in other countries, so the contribution in India captures only part of their total values. Nevertheless, the value in India is high and HYV research does yield a high rate of return.

As shown in Table 7, the marginal rates of return to public agricultural research are very high, 70 percent over all three periods. Although returns to research have declined slightly over time, they remain very high relative to conventional investment criteria, at 53 percent for the post-green revolution period. The returns to public extension are similarly high, at 61 percent over the full period and 52 percent for the final sub-period.

Private R&D in India (and the modernization of management associated with it) produces a return to the private firms investing in the research. The public benefits realized in the agricultural sector are in addition to these private gains. Clearly the social benefits realized in the agricultural sector from private research are large and sufficient by themselves to call for more investment in private sector R&D. Evenson (1993) reviews sector R&D find that a large proportion of the benefits from such research are public goods, uncaptured by the investing firms.

International R&D in the private sector also generates returns to private firms and social or public goods benefits. The returns generated in India on this investment are only a small part of the total gains realized on this investment. Even the Indian gains, however, are large enough to justify this investment.

Similarly, returns to irrigation investment have been realized by the private firms and government agencies making the investment. We have incorporated these returns (through the value as an input of irrigation investment) into the TFP

Table 7--Estimated marginal rates of return to investment (percent)

	1956-66	1966-77	1978-87	1956-87
Irrigation[a]	4	5	6	5
Extension	72	60	52	61
Public Research	97	67	53	70
HYVs	-	72	0	25
Domestic Private R+D	24	74	0	36
Foreign Private R+D	18	7	15	13

[a] Incremental contribution above and beyond the value of irrigation as a direct input.

measures in this study. The returns reported in Table 7 are additional -- technology related benefits. We interpret these gains as being associated with expansion of production environments that are favorable to newly developed technology.

4. CONCLUSIONS AND POLICY IMPLIATIONS

Substantial productivity gains, as measured by total factor productivity indexes, have been realized in India's agriculture. These gains have varied somewhat by period (being highest in the green-revolution period) but in each period examined, India has realized gains. The rate of change in TFP has been relatively high. Total factor productivity growth has contributed roughly 1.1 percent per year to crop production growth in India, matching the contribution from growth in conventional inputs since 1956.

Analysis of sources of total factor productivity gains shows that several types of investments were associated with and contributed to TFP growth. Public agricultural research and extension explains nearly 60 percent of TFP growth over the 1956-87 period. This study is one of the first to investigate the contributions of private sector research and development to productivity growth. We find also that private sector research and development by foreign agribusiness firms in the farm machinery and farm chemical industries have made a large contribution to TFP growth, accounting for nearly one-fourth of TFP growth over the full period. Private sector research and development by Indian firms also contributed, partly by facilitating the foreign contributions and partly by complementing public sector research. The private sector contribution is associated with the modernization of agriculture through adoption of improved inputs, and likely through the improvement of farm management practices.

Improved rural markets and irrigation investment have also contributed to TFP growth, with irrigation investment generating TFP growth over and above the contribution to output growth that irrigation makes as a "conventional" input. This additional contribution from irrigation comes largely through providing an improved environment for crop technology.

We examined the hypothesis that the contributions of public research, extension and irrigation to TFP growth declined over time by disaggregating the impact of these factors into pre-green revolution (1956-66), green revolution (1967-77), and post-green revolution (1978-87) periods. The marginal impact of public research and extension on TFP declined slightly over time, but even during the post-green revolution period the rates of return to these investments was over 50 percent. The marginal impact on productivity from the expansion of irrigated area has increased over time. This improvement can be attributed to rapid growth in the proportion of private tubewell (groundwater) irrigation compared to public canal irrigation.

Modern crop varieties contributed to TFP growth in the 1967-1977 green-revolution period. The decline thereafter in the contribution of modern varieties, while the public sector research and the irrigation contribution remained high appears to be reflective of a shift from early reliance on "foreign" origin modern varieties to Indian origin modern varieties, and a broadening of the mechanism by which research contributes to TFP. The contributions of Indian public research are captured in the latter period mainly through the research effect rather than being embodied in modern crop varieties.

It is thus clear that, from a growth accounting perspective, India has achieved significant total factor productivity growth and that this growth enabled the economy to increase food production even though India began the period with high population densities and limited potential for cropland expansion as a source of output growth. It is also clear that this TFP growth was produced by investments -- primarily in research -- but also in extension, markets, and irrigation. The high rates of return, particularly to public agricultural research and extension, indicate that the Government of India is not overinvesting in agricultural research and investment, but rather that current levels of public investment could be profitably expanded.

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