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Background Note for Supporting the Development of CGIAR Strategy and Results Framework

R&D Investment in National and International Agricultural Research: Productivity and Poverty Impact and Allocation among Regions

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1. Introduction

Agricultural research has played important role in promoting production and productivity, thus poverty reduction in developing countries for the past several decades. Compared to other investments, returns to agricultural R&D have been highest. However, as we move to a new era, we face new challenges. More than one billion people still live under one dollar per day and more than 800 million people are malnourished. Population will continue to grow and most of growth will come from developing countries. The key question is how agricultural R&D will continue to play the role as it has in the past. How much investments are really required and how they can be allocated among different regions in order to maximize agricultural output gains and reduction in poverty. This paper attempts to answer these questions using a transparent modeling of the agricultural research investment effects globally and by region.

Simulating required R&D investment and optimally allocating them require information on how agricultural research investment would affect agricultural production. This area of research could be seen as a particular application of production economics where the main focus is on the physical relationship between agricultural output and R&D investment in addition to conventional inputs like land, labor fertilizer, etc. In an early survey of this literature, Norton and Davis (1981) classify returns to research studies into two main approaches: a) the economic surplus approach; and b) the production function approach, which has been extended to the use of duality and the estimation of cost and profit functions. The economic surplus approach analyses changes in producer and consumer benefits as the result of a research-induced shift in the supply curve. The production function approach evaluates the additional output or the saving in inputs attributable to past investments in R&D by estimating an aggregate production (profit, cost) function model (Roseboom, 2003). Alston, Norton, and Pardey (1995) discuss both approaches in great detail. A critical step in both methods is the modeling of the relationship between investment in R&D and the benefits that result (Roseboom, 2003).

A different classification of methods to analyze returns to research that is particularly useful for the analysis conducted in this study, is one that classifies methods in two broad categories: ex ante and ex post methods, depending if they are adequate to analyze returns to investment before or after the investment takes place (Norton and Davis, 1981). The production function and economic surplus approaches already mentioned are classified as ex post methods. Conversely, simulation and mathematical programming approaches have been used to define a priori the most efficient allocation of R&D investment across different projects or different regions.

When using simulation methods, researchers define overall goals of research and then analyze changes in production and consumption necessary to achieve those goals. The last step is to evaluate alternative technologies capable to affect production and consumption to achieve the pre-defined goals (Norton and Davis, 1981). These models employ specific relationships between production or productivity and R&D investment using estimated production functions. They then use these estimated functions to simulate the effect on production, consumption and other variables defining optimal allocation of investment using different approaches (benefit-cost ratios, internal rates of return, discounted cash flows, etc.)

Similarly, mathematical optimization models have been used in the past to determine optimal allocation of a given research budget. Mathematical programming deals with the selection of decision variable values so as to maximize an objective subject to constraints. This approach has advantages when dealing with selection by policy makers among a set of alternative actions and goals as is the case of allocation of R&D investment among different regions or sectors. The main characteristic of a mathematical program is that it constructs a synthetic representation of supply response to R&D based on an assumed objective and sets of variables and constraints. The approach is particularly useful when there is not enough information to econometrically specify the relationships between agricultural output and R&D, or when the range of possible solutions requires modeling seeking behavior rather than relying on process following simulation (McCarl, 1992).

2. Research Investment, productivity, and benefits

In this section, we review trends in agricultural research and development (R&D) spending by both National Agricultural Research Systems (NARS) and the international research centers of the Consultative Group on International Agricultural Research (CGIAR), as well as trends in productivity. We then present a simple model to simulate the impact of doubling agricultural R&D investments in five years on agricultural production growth and poverty reduction. We deliberately do not attempt to separate the effects of CGIAR vs. NARS investments since these two forces are highly complementary to each other in close partnership; international and national agricultural research must expand in tandem.

In the past decade, total agricultural R&D spending in developing countries increased from US$3.3 billion (1992) to US$3.9 billion (2000), or by 2.1 percent annually.[1] This spending was largely driven by Asia, where annual spending increased by 3.5 percent. In Africa, agricultural R&D expenditure grew by a much slower rate of 1.9 percent per year: East Africa’s expenditure grew the most at 4.6 percent, while West Africa’s grew marginally at 1.7 percent, and Southern Africa’s spending remained constant. Latin America’s expenditure grew by only 0.6 percent during this period.

[1] All research spending is measured in constant 2005 U.S. dollars. This is different from the traditional measure of purchasing power parity (PPP) or international dollars reported by various ASTI reports..

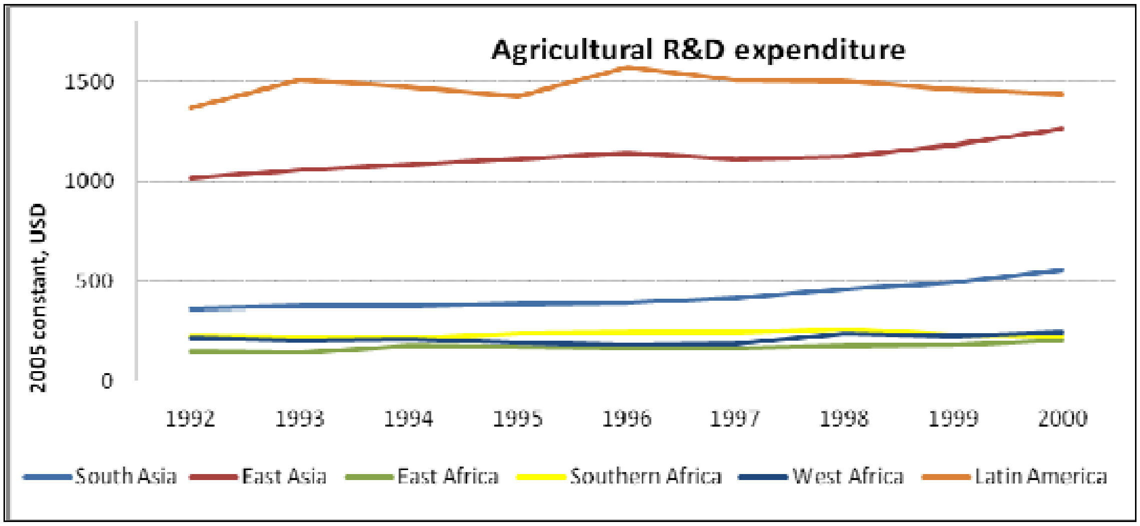
As a result, many countries are sharply divided in terms of their capacity to use science to promote productivity growth to achieve food security and reduce poverty and hunger. Today, Asia accounts for 46 percent of total agricultural R&D spending in developing countries, while China and India account for 25 and 14 percent of total spending, respectively. Although Africa is geographically large, its share is only 17 percent. Latin America accounts for 36 percent (with Brazil being responsible for 41 percent of that share).

For every US$100 of agricultural output, developed countries spend US$2.36 on public agricultural R&D, whereas developing countries spend only US$0.53 (Pardey et al. 2006). This highlights the underinvestment in agricultural R&D in developing countries, and the gap in generating new technology between rich and poor nations.

Regarding investment in the international centers, CGIAR funding increased from US$337 million in 1992 to US$445 million in 2006, representing an annual growth of only 2 percent. In 2000, the CGIAR represented 9.6 percent of agricultural research spending in developing countries. CGIAR spending is relatively small in Asia and Latin America (representing 6.8 percent and 4.4 percent, respectively, of their total national system investment), but is large in Africa (23 percent).

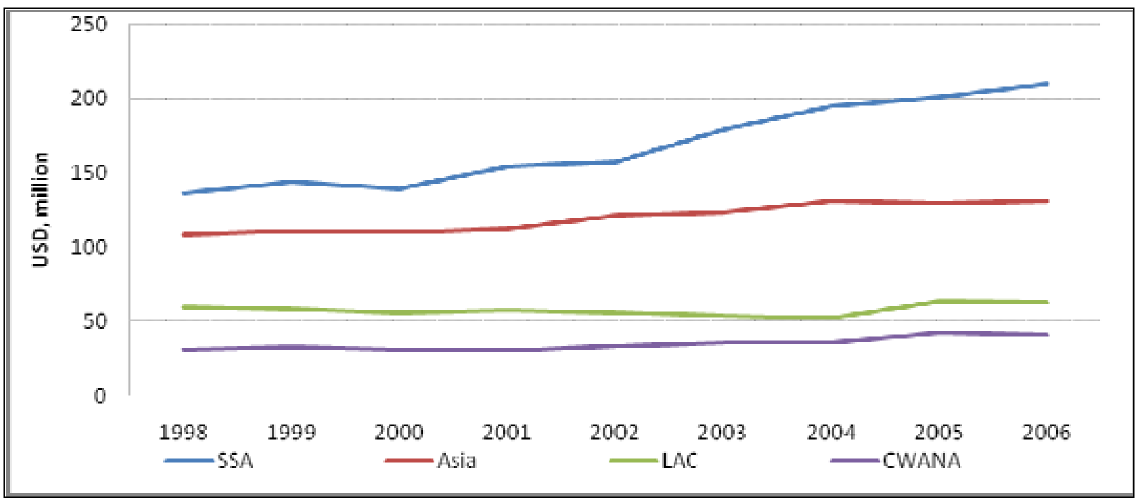
Productivity has risen in many developing countries, mainly as a result of investment in agricultural research combined with improved human capital and rural infrastructure. In East Asia, land productivity increased from US$1,485/ha in 1992 to US$2,129/ha in 2006, while labor productivity rose from US$510 to US$822/worker. In Africa, the levels of productivity are much lower, and their growth has also been slower. In 1992, land productivity in SSA was only 79 percent of that in East Asia (indicating a 21-percent gap); by 2006 the gap had increased to 59 percent. Growth in total factor productivity (TFP, derived from total output growth to total input growth), exhibits even larger variation among regions. From 1992 to 2003, East Asia and Latin America experienced the most rapid growth at 2.7 percent per year. East Africa had the lowest growth. TFP in other regions grew between 1 to 1.6 percent.

Figure 2.1. Agricultural R&D spending in developing countries



Source: Agricultural Science & Technology Indicators (ASTI) datasets.

Figure 2.2 Agricultural R&D Expenditure by the CGIAR



Source: CGIAR.

Table 2.1. Agricultural productivity growth in developing countries (%)

	Land		Labor		TFP
	1992	2006	1992	2006	1992-2003
	(2005 constant US$/ha)		(2005 constant US$/worker)		Annual Growth %
East Asia	1485	2129	510	822	2.7
South Asia	813	1156	539	644	1.0
East Africa	503	514	347	351	0.4
West Africa	408	521	601	730	1.6
Southern Africa	255	229	234	190	1.3
Latin America	1129	1614	3294	5402	2.7
NAWA	785	1121	1785	2184	1.4
Average	846	1198	591	827	2.1

Source: Author's calculation based on FAOSTAT data.

Returns to agricultural research have proven to be very high. On average, the rate of returns (ROR) to NARS in developing countries is 60 percent (see table below), which is higher than investments in education and roads.[2] The Asia and Pacific region has the highest ROR (78 percent), while Africa has the lowest, but even the African RORs are high (49.6 percent). The median ROR exhibits similar patterns among regions; Asia and Pacific has the highest while Africa has the lowest and Latin America falls between. The ROR for international agricultural research centers (IARC) in the CGIAR is much higher than that for NARS. In Africa, the median IARC ROR is 83 percent higher than for NARS, while in Asia and Pacific the gap is 72 percent. The gap in Latin America is only 21 percent. This pattern points at the need for investment in increased capacity strengthening of NARS.

Table 2.2. Rate of return of NARS and IARC

Rate of Return	Alston et al.	Evenson	Evenson and Gollin
	NARS Mean	NARS Median	IARC
Developing countries	60.1	..	..
Africa	49.6	37	68
Asia and Pacific	78.1	67	115
Latin America	53.2	47	39
IARC	77.8	..	..

Notes: IARC=International agricultural research centers.
Sources: Alston et al. (2000); Evenson (2001); and Evenson and Gollin, (2007).

[2] For comparisons of returns to different types of investment, see S. Fan, *Public Expenditures, Growth and Poverty in Developing Countries: Issues, Methods and Findings* (Baltimore: The Johns Hopkins University Press, 2008).

3. The model

Based on the considerations discussed in the previous section, in this study we use a mathematical optimization model to find the optimal allocation of R&D investment among major developing regions in order to maximize global agricultural production, or alternatively minimize global poverty. This approach follows the work by Fan, Zhang and Robinson (2003) that developed an optimization model to quantify the contribution to aggregate growth from reallocating resources among sectors over time. This is a typical central –planner problem where perfect competition leads to a Pareto-optimal allocation of goods and services. Fan, Zhang and Robinson estimate sectoral production functions and by assuming a certain social welfare function, they solve the central planner's problem to obtain optimal input allocations among sectors.

In this study, we focus on R&D investments instead of conventional inputs, and define the optimization as social planner's problem maximizing a social welfare function to optimally allocate R&D investment across developing regions. We assume that the level of agricultural output in each region is the result of the use of conventional inputs (land, labor, tractors, animal stock and fertilizer), which we fix at their base observed level, and the stock of R&D. With inputs fixed, agricultural output then varies with R&D stock. We define R&D stock as a function of past investment in R&D. This is because there is a time lag between investment and actual impact on production and poverty. The response of output to R&D growth is specific for each region and depends on R&D elasticity values obtained from the literature.

The social planner problem is also solved defining a global welfare function that minimizes the number of poor people across regions subject to each region's agricultural output response to R&D and the response of poverty to agricultural output growth in each region. As in the case of output response to R&D, changes in poverty due to agricultural growth are also defined using poverty elasticities from the literature.

The first social planner problem maximizes agricultural output across developing regions. This optimization problem maximizes the following welfare function:

$$\text{Maximize} \quad W_t^{max} = \sum_i \left[\mu_{i,t} \times \ln\left(Y_{i,t}\right)\right] \qquad (1)$$

while for the second problem, the main concern of the social planner is poverty minimization in developing regions:

$$\text{Minimize} \quad W_t^{min} = \sum_i \left[\rho_{i,t} \times \ln\left(Z_{i,t}\right)\right] \qquad (2)$$

where $Y_{i,t}$ is region's ***i*** agricultural output in year t, $Z_{i,t}$ is the number of poor under US$1 a day in region ***i***, $\mu_{i,t}$ is the share of region i in total agricultural output, and $\rho_{i,t}$ is the share of region ***i*** in total number of poor.

Both the output maximization and poverty minimization problems are subjected to the same constraints:

$$Y_{i,t} = \gamma_{i,t} \prod_j X_{i,j,t}^{\alpha_{i,j}} \left[RDSK_{i,t}^{\delta_i}\right] \tag{3}$$

A Cobb-Douglas production function where $X_{i,j}$ represent the quantities of the different ***j*** inputs used in the agricultural production process in region ***i***. We fix input quantities in each region at the base period level: $X_{i,j,t} = \bar{X}_{i,j,0}$ so agricultural output in region ***i*** is assumed to vary only with changes in R & D stock ($RDSK_{i,t}$). Poverty in each region ***i*** is a function of agricultural output and is expressed as:

$$Z_{i,t} = \theta_i Y_{i,t}^{\varepsilon} \tag{4}$$

The final optimization problem for year ***t***, in the case of agricultural output maximization is:

Maximize: $W_t^{max} = \sum_i [\mu_{it} \times \ln (Y_{it})]$

s.t. (5)

$$Y_{i,t} = \gamma_{i,t} \prod_j X_{i,j,t}^{\alpha_{i,j}} \left[RDSK_{i,t}^{\delta_i}\right]$$

The poverty minimization problem is defined as follows:

Minimize $W_t^{min} = \sum_i [\rho_{i,t} \times \ln (Z_{i,t})]$

s.t. (6)

$$Y_{i,t} = \gamma_{i,t} \prod_j X_{i,j,t}^{\alpha_{i,j}} \left[RDSK_{i,t}^{\delta_i}\right]$$

$$Z_{i,t} = \theta_i Y_{i,t}^{\varepsilon}$$

In both problems, the R&D stock in year ***t*** is defined as the weighted sum of annual R&D investment in the previous 12 years assuming that there is a time lag between the investment and its effects on output. The value of the weights was defined as to increase between ***t-1*** and to ***t-6*** and to decrease between ***t-7*** and ***t-12***, following a symmetric pattern with respect to the midpoint. By this definition, we assume that the full impact of new investment starting in 2008 will occur in 2020.

$$RDSK_{i,t} = \sum_{k=1}^{12} (\beta_{t-k} \times IRD_{i,t-k}) \tag{7}$$

The poverty equation is also used in problem (5) to calculate the number of poor with the optimal level of output that results from the maximization problem.

For the period that goes from 2013 and 2020 we assume that new investment is region specific and follows the historical trend. As in the case of output response to R&D, changes in poverty due to agricultural growth are also defined using poverty elasticities from the literature. No price effects are considered in the optimization problem and the model assumes no spillovers of R&D investment to other regions.

4. Uncertainty of elasticity values

This paper follows a simple method for generating asymptotically consistent estimator of the population mean of the distribution of solution values, where the only source of uncertainty is the set of elasticity estimates (see De Vuyst and Preckel, 1997 and Harrison and Vinod, 1992). The first step in our procedure is to draw on the literature to obtain information on the two key elasticities used in our simulations: the output elasticity with respect to R & D investment and the poverty elasticity with respect to output. We assume that it is possible to determine an appropriate *a priori* distribution for each elasticity (Harrison and Vinod, 1992). The information obtained from the literature is used to approximate the uncertain parameter distributions with a discrete set of points by defining distributions for each parameter that allow us to sample from the full range of possible elasticity values. Having defined the distributions of the elasticities we repeatedly draw Monte Carlo samples from these distributions, solve the model using these drawn parameters to produce estimates of means and standard deviations of model results. Finally, we use these estimates to compute approximate confidence bounds on the mean values of output, investment and poverty alleviation using Chebyshev's Inequality.

The first step in our analysis is to determine the R & D and poverty elasticities. Table A1 in the appendix presents a summary of some of the findings resulting from a literature review on this issue. The distribution of R&D elasticities for Asian countries are from Evenson, Pray and Rosegrant (1998); Fan and Pardey (1997 and 1998); and Fan (2000) and appear to be the most robust estimates from the literature. R&D elasticities for Africa are only 3 and appear to be too low. No elasticities were found in the literature for Latin America.

Given that the available information on elasticities appears to be limited, we use the average value of the R&D elasticity of Asian countries as the reference value to calibrate elasticity values for all other regions using information on rates of returns to investment in R&D. The paper by Evenson (2001) reviews the literature using rates of return and presents a summary table with ranges of the values of rates of returns and the number of studies finding values within those ranges (Table 4.1).

We then use the average elasticity for Asia as the reference and estimate R&D elasticities for other regions assuming that the differences in elasticities between regions are proportional to the IRR. The frequencies and values from Table 4.1 are used to define the distribution and values for R&D elasticities.

Table 4.1. Frequency of different ranges of Internal Rates of Return (IRR) to R&D in the literature

	Range of IRR						
Region	0-20	21-40	41-60	68-80	81-100	100+	Total
OECD	13.0	31.9	20.3	10.9	8.0	15.9	100
Asia	15.1	16.0	18.9	14.2	9.4	26.4	100
Latin America	13.3	35.0	16.7	23.3	8.3	3.3	100
Africa	22.2	22.2	33.3	11.1	11.1	0.0	100
All	14.1	26.8	19.5	14.4	8.6	16.6	100

Source: Evenson (2001)

Data availability for the poverty-output elasticity are also very limited given that the number of papers looking at this issue is than that looking at IRR and R&D-output elasticities. The main reference for the elasticity values used in our study is the paper by Thirtle, Lin and Piesse (2003), estimating the impact of research-led agricultural productivity growth on poverty reduction in Africa, Asia and Latin America. As their estimates are elasticities of poverty with respect to R & D investment, we convert their elasticities in poverty-output elasticities by dividing them by the average of our output-R&D elasticity distributions. We then define the distribution of the poverty-output elasticities by using Thirtle, Lin and Piesse's converted elasticities as central moments of these distributions. Finally, we define maximum and minimum values assuming that the poverty-output distributions for the different regions have the same variance as the respective output-R&D distributions. Minimums and maximums are then calculated as the $Mean \pm (2.6 \times SD)$, where 2.6 times the standard deviation defines the range of most likely values around the mean (99 percent probability in a normal distribution).

The ranges of values found in the literature are used to define triangular distributions for the elasticity values in each region. The triangular distribution is typically used as a subjective description of a population for which there is only limited sample data, given that the definition of the distribution only requires knowledge of the minimum and maximum values and a guesstimate of the modal value, which in many cases is defined by assuming a symmetric distribution around the mean.

Table 4.2 shows the parameters and first and second moments of the distributions for the R & D and poverty elasticities defined as explained above. The highest values for the output-R&D elasticities are found in Asia and in particular in China for which available information allowed us to define a country-specific distribution. Countries in SSA show the highest poverty elasticities, twice as high as those for Asia, while the lowest poverty-output elasticity values are found in Latin America.

Table 4.2. Parameters and moments of the assumed triangular distributions of output-R&D and poverty-output elasticities for different developing regions.

	Output/R&D elasticity		Poverty/Output elasticity	
	Mean	SD	Mean	SD
Output-R&D elasticities				
Sub-Saharan Africa & WANA	0.098	0.057	2.646	1.069
Asia	0.142	0.084	1.101	0.457
China	0.170	0.096	0.970	0.408
Latin America	0.108	0.108	0.274	0.111

Notes: The mean and variance of a triangular distribution are calculated as follows:
Mean = $Mean = (a + b + c)/3$; VAR$= (a^2 + b^2 + c^2 - ab - ac - bc)/18$, where *c* is the mode and *a* and *b* are respectively the minimum and maximum values.

5. Approach and results

The regions considered in the analysis are: Sub-Saharan Africa (comprising Southern, West Coastal, Sahel, East Africa and South Africa), West Asia and North Africa (WANA), China, India and other Asian countries clustered in two groups (South Asia, East and Southeast Asia), and Latin America and the Caribbean including the Southern Cone (Brazil, Argentina, Chile and Uruguay; Andean countries including Central America and Mexico. We combine national agricultural research spending and CGIAR spending together as total spending that affects agricultural productivity in developing countries in our simulation.[3] Three scenarios are considered, projecting R&D investment, agricultural growth and the number of poor in each region to 2020:

- The first scenario assumes that total factor productivity increases annually in all regions by 0.5 percent until 2020. This is the average growth of technical change in developing countries in the past 10 years (see Figure A1 in the Appendix).
- The second scenario assumes that an amount equal to total R&D invested by developing regions in 2008 is allocated among these regions to maximize total agricultural output produced in developing countries. Investment in R&D is allocated via an optimization problem that ***maximizes total agricultural output,*** subject to each region's agricultural output response to R&D, and the level of R&D stock in each region. It is also assumed that the full impact of the optimal allocation is achieved in 2020, and that R&D stocks are built investing a fix percentage of the targeted amount between 2009 and 2020.
- The third scenario assumes as in the previous scenario that an amount equal to total R&D invested by developing regions in 2008 is allocated among these regions via an optimization problem, but in this case the problem is ***minimizes poverty***, subject to each region's agricultural output response to R&D and the response of poverty to agricultural output growth in each region. As in the previous scenario we assume that the full effect of optimal allocated investment is reached in 2020.

A business-as-usual scenario (BAU) projecting growth of R&D stocks to 2020 assuming historical rates of investment in each region is also estimated as a reference for the results of the main three scenarios and results for all other scenarios include also growth in business-as-usual. Each scenario is estimated using two different poverty lines: 1.25 and 2 dollars a day. Results from the BAU scenario are used as the reference for results in other scenario and are presented in Tables 5.1 and 5.7 (for the $1.25 and $2.00 poverty lines respectively).

Under the first scenario, ***increasing agricultural productivity annually by 0.5 percent across all regions until 2020,*** more than 12 billion dollars will be required (above BAU growth) to sustain a 0.5 percent productivity increase during 12 years, a total output growth of 12.7 percent in 12 years (Table 5.2). The results in terms of growth and poverty alleviation are better than in the

[3] CGIAR reports their spending for Sub-Sahara Africa, Asia, Latin America, and WANA regions. We use the share of NARS spending to allocate CGIAR spending to each country or sub-region.

business-as-usual scenario, especially in terms of poverty alleviation. The 0.5 percent increase in productivity across the board results in higher R&D investment than the historical averages in regions with high levels of poverty like Sub-Saharan Africa. In this region, the number of poor will be reduced by 100 million in 12 years, compared to 52 million at historical rates of investment.

However, the results from the 0.5 percent across the board increase in productivity appears to be very inefficient in the use of R&D investment as can be seen by comparing this scenario with the results of the optimal allocation scenarios. Under the second scenario, ***maximizing total agricultural output,*** average annual agricultural output will increase by 1.84 percent per year from 2008 to 2020; China, India and Southeast Asia are projected to grow faster than average at 2.57 and 1.92 percent per year respectively (Table 5.3).

The impact of the maximizing output scenario on poverty is higher than that in the business-as-usual scenario, moving 175 million people out of poverty by 2020, compared to 149 million under historical rates of investment (which brings the total to 324 million with BAU plus output optimization). Of this 175 million, 85 million live in South Asia (with 74 million in India), only 37 million in Sub-Saharan Africa (32 million in West Africa), and 55 million in Southeast Asia. The poverty impacts are still below those in the 1 percent productivity growth scenario, but the inefficiency of allocating investment equally across regions is clear given that higher investment was needed in the 1 percent growth scenario (about $2 billion) compared to the optimal allocation scenario. It is also clear from this scenario that to maximize agricultural output growth in developing countries, R&D investment should be allocated to Southeast Asia and South Asia.

Under the third scenario (Table 5.4), ***minimizing poverty***, more R&D investment should be allocated to Sub-Saharan Africa (SSA) and South Asia. Most of the poor earning less than $1.25 a day live in South Asia (700 million) and in SSA (365 million), which means that to effectively reduce poverty, a significant share of R&D investment should be allocated to those regions. The optimal allocation of R&D investment would reduce the number of poor by 414 million in 12 years assuming that investment at historical rates will also continue in the coming years. Of these, 177 million would be in South Asia and 170 million in SSA (with 93 million in the west coast of Africa). The poverty rate in South Asia would decrease from 48 percent in 2005 to 31 percent by 2020, which is 7 points below that in the business-as-usual scenario. The poverty rate in Africa would decrease from 56 percent in 2005 to 27 percent, a large improvement compared to the expected poverty rate under business-as-usual of 40 percent in 2020. Minimizing poverty requires that a large share of total R&D investment be directed to Africa.

Better results can be achieved if the efficiency of the response of output to R&D investment is improved. A study by Fan (2000), shows that rates of returns to R&D investment in China grew between 1975 and 1997 at an annual rate of almost 4 percent. We analyze the impact of increasing R&D elasticities over time by running the output and poverty optimization scenarios assuming increases in R&D elasticities in all regions at a similar rate of that in China as reported in Fan (2000). The final elasticity value used is within the range of the elasticity distributions defined for each region and significantly lower than the extreme values in those distributions. Results of the business-as-usual and the 0.5 increase in productivity scenarios are presented in Tables 5.5 and 5.6. An improvement on the efficiency of R&D investment results in significant increases in the rate of growth and the number of poor people lifted out of poverty in both scenarios.

Finally, the use of 2 dollars instead of 1.25 dollars as the poverty line introduces changes only on the poverty results in the optimization scenarios (Tables 5.11 and 5.12). In general, we observe that using 2 dollars a day as the poverty line, the allocation patterns observed are similar to those in previous scenarios, with the major difference being that relatively more investment tends to be allocated to Asia rather than to SSA. When using 1.25 dollars a day as the poverty line, the share of SSA in the total number of people lifted out of poverty under the poverty minimization scenario is 21 percent but reduces to 16 percent (favoring Asia) when 2 dollars a day is used.

6. Conclusion

This paper analyzes the effect of agricultural R&D investment on growth and poverty alleviation in developing regions and to estimate how much investment is required and how it can be allocated among different regions to maximize agricultural output gains and reduction in poverty. To do this we use a transparent modeling of the global and regional agricultural research investment effects.

Our results clearly show the importance of setting the right regional priorities of investment for achieving different development goals. Allocating investment for achieving similar productivity growth across all regions results in a very inefficient use of R&D investment. To maximize agricultural output growth in developing countries, R&D investment should mainly be allocated to Southeast and South Asia. On the other hand, to minimize poverty in developing regions, investment must be directed to Sub-Saharan Africa. Moreover, better results in terms of growth and poverty alleviation can be achieved if the efficiency of the response of output to R&D investment is improved. Our results show that efficiency improvements, within the range of those observed in China during the 1990s, result in significant increases in the rate of growth and the number of poor people lifted out of poverty. Finally, we observe similar allocation patterns of R&D investment when using 1.25 and 2 dollars a day as the poverty line. The major difference observed in the results with different poverty lines is that the larger number of poor in Asia relative to Africa using the 2 dollars a day poverty line results in relatively more investment being allocated to Asia rather than to SSA in both the output maximization and poverty minimization scenarios. Our simulation results are robust for a wide range of elasticities.

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Table 5.1. R&D investment and impact on poverty and output growth under business as usual when poverty line is $1.25/day

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	1,224	365	-53.5	0.50
- East Africa	287	532	140	-20.2	0.51
- Southern Africa	88	119	12	-1.9	0.51
-West Coast Africa	139	210	169	-25.1	0.50
-Sahel Africa	94	143	34	-4.8	0.48
South Africa	164	221	10	-1.4	0.49
W.Asia & N.Africa	546	722	9	-1.3	0.50
Asia	2,864	4,323	1,002	-93.6	0.80
E & SE Asia	1,956	303	304	-12.7	0.73
-China	1,457	2,200	208	-19.5	0.86
South Asia	908	753	698	-9.2	0.73
-India	707	1,068	569	-52.3	0.72
Latin America	957	1,037	44	-0.8	0.53
Southern Cone	637	690	16	-0.3	0.52
Andean	174	189	26	-0.5	0.53
Mexico	146	158	2	0.0	0.54
Total	5,139	7,307	1,420	-149.1	0.70

Source: Authors' from simulation results

Table 5.2. R&D investment and impact on poverty with 0.5 percent growth in productivity when poverty line is $1.25/day

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	2,822	365	-105.9	1.01
- East Africa	287	1,130	140	-40.3	1.01
- Southern Africa	88	301	12	-3.7	1.01
-West Coast Africa	139	496	169	-49.4	1.01
-Sahel Africa	94	337	34	-9.6	0.98
South Africa	164	558	10	-2.8	1.30
W.Asia & N.Africa	546	1,845	9	-2.5	1.23
Asia	2,864	10,210	1,002	-158.0	1.23
E & SE Asia	1,956	5,908	304	-52.5	1.36
-China	1,457	5,192	208	-31.1	1.22
South Asia	908	4,302	698	-105.4	1.03
-India	707	2,522	569	-90.0	1.02
Latin America	957	2,986	44	-1.5	1.03
Southern Cone	637	1,987	16	-0.5	1.04
Andean	174	543	26	-0.9	1.00
Mexico	146	456	2	-0.1	1.00
Total	5,139	17,863	1,420	-268	1.20

Source: Authors' from simulation results

Table 5.3. R&D investment and impact on poverty and output growth under output maximization when poverty line is $1.25/day

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	1,444	365	-90.0	0.92
- East Africa	287	562	140	-24.2	0.62
- Southern Africa	88	124	12	-2.1	0.58
-West Coast Africa	139	389	169	-57.0	1.34
-Sahel Africa	94	147	34	-5.3	0.53
South Africa	164	222	10	-1.4	0.51
W.Asia & N.Africa	546	884	9	-1.9	0.78
Asia	2,864	8,515	1,002	-230.6	2.28
E & SE Asia	1,956	5,305	304	-84.6	2.13
-China	1,457	4,682	208	-52.2	2.57
South Asia	908	3,209	698	-146.0	1.73
-India	707	1,982	569	-126.2	1.92
Latin America	957	1,604	44	-1.6	1.05
Southern Cone	637	1,042	16	-0.5	1.02
Andean	174	322	26	-1.0	1.17
Mexico	146	241	2	-0.1	1.05
Total	5,139	12,446	1,420	-324	1.84

Source: Authors' from simulation results

Table 5.4. R&D investment and impact on poverty and output growth under poverty minimization when poverty line is $1.25/day.

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	3,565	365	-170.0	1.97
- East Africa	287	1,367	140	-58.9	1.76
- Southern Africa	88	172	12	-3.5	0.96
-West Coast Africa	139	1,449	169	-92.9	2.63
-Sahel Africa	94	346	34	-13.0	1.50
South Africa	164	231	10	-1.6	0.57
W.Asia & N.Africa	546	722	9	-1.3	0.50
Asia	2,864	7,122	1,002	-242.3	1.58
E & SE Asia	1,956	3,266	304	-65.1	2.54
-China	1,457	2,423	208	-26.5	1.12
South Asia	908	3,856	698	-177.2	1.21
-India	707	2,910	569	-161.8	2.47
Latin America	957	1,038	44	-0.8	0.53
Southern Cone	637	690	16	-0.3	0.52
Andean	174	189	26	-0.5	0.53
Mexico	146	158	2	0.0	0.54
Total	5,139	12,446	1,420	-414	1.36

Source: Authors' from simulation results

Table 5.5. R&D investment and impact on poverty and output growth under business as usual when poverty line is $1.25 and regions with higher R&D efficiency

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	1,224	365	-82.4	0.81
- East Africa	287	532	140	-31.9	0.82
- Southern Africa	88	119	12	-2.8	0.80
-West Coast Africa	139	210	169	-38.1	0.81
-Sahel Africa	94	143	34	-7.4	0.81
South Africa	164	221	10	-2.1	0.80
W.Asia & N.Africa	546	722	9	-1.9	0.80
Asia	2,864	4,323	1,002	-146.7	1.28
E & SE Asia	1,956	2,502	304	-50.0	1.17
-China	1,457	2,200	208	-30.8	1.37
South Asia	908	1,821	698	-96.7	1.17
-India	707	1,068	569	-82.6	1.17
Latin America	957	1,037	44	-1.2	0.84
Southern Cone	637	690	16	-0.4	0.84
Andean	174	189	26	-0.7	0.84
Mexico	146	158	2	0.0	0.84
Total	5,139	7,307	1,420	-232.2	1.13

Source: Authors' from simulation results

Table 5.6. R&D investment and impact on poverty with 0.5 percent growth in productivity when poverty line is $1.25 and regions with higher R&D efficiency

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	2,347	365	-134.9	1.31
- East Africa	287	949	140	-52.1	1.32
- Southern Africa	88	248	12	-4.7	1.30
-West Coast Africa	139	411	169	-62.4	1.31
-Sahel Africa	94	279	34	-12.2	1.31
South Africa	164	459	10	-3.6	1.30
W.Asia & N.Africa	546	1,516	9	-3.2	1.30
Asia	2,864	7,967	1,002	-211.0	1.78
E & SE Asia	1,956	4,969	304	-70.3	1.67
-China	1,457	4,019	208	-42.5	1.87
South Asia	908	2,999	698	-140.7	1.67
-India	707	1,985	569	-120.3	1.67
Latin America	957	2,398	44	-1.9	1.34
Southern Cone	637	1,595	16	-0.7	1.34
Andean	174	436	26	-1.1	1.34
Mexico	146	366	2	-0.1	1.34
Total	5,139	14,228	1,420	-351	1.63

Source: Authors' from simulation results

Table 5.7. R&D investment and impact on poverty and output growth under business as usual when poverty line is $2.00/day.

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	1,224	526	-77.1	0.50
- East Africa	287	532	203	-29.2	0.51
- Southern Africa	88	119	21	-3.3	0.51
-West Coast Africa	139	210	235	-35.0	0.50
-Sahel Africa	94	143	50	-7.1	0.48
South Africa	164	221	17	-2.5	0.49
W.Asia & N.Africa	546	722	41	-5.9	0.50
Asia	2,864	4,323	1,979	-185.0	0.80
E & SE Asia	1,956	303	700	-24.1	0.73
-China	1,457	2,200	474	-44.4	0.86
South Asia	908	753	1,278	-21.6	0.73
-India	707	1,068	1,033	-94.9	0.72
Latin America	957	1,037	92	-1.6	0.53
Southern Cone	637	690	39	-0.7	0.52
Andean	174	189	47	-0.8	0.53
Mexico	146	158	6	-0.1	0.54
Total	5,139	7,307	2,638	-269.5	0.70

Source: Authors' from simulation results

Table 5.8. R&D investment and impact on poverty with 0.5 percent growth in productivity when poverty line is $2.00/day

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	2,822	526	-152.7	1.01
- East Africa	287	1,130	203	-58.2	1.01
- Southern Africa	88	301	21	-6.4	1.01
-West Coast Africa	139	496	235	-68.8	1.01
-Sahel Africa	94	337	50	-14.2	0.98
South Africa	164	558	17	-5.0	1.30
W.Asia & N.Africa	546	1,845	41	-11.8	1.23
Asia	2,864	10,210	1,979	-311.4	1.23
E & SE Asia	1,956	5,908	700	-111.5	1.36
-China	1,457	5,192	474	-71.0	1.22
South Asia	908	4,302	1,278	-199.9	1.03
-India	707	2,522	1,033	-163.4	1.02
Latin America	957	2,986	92	-3.1	1.03
Southern Cone	637	1,987	39	-1.3	1.04
Andean	174	543	47	-1.6	1.00
Mexico	146	456	6	-0.2	1.00
Total	5,139	17,863	2,638	-479	1.20

Source: Authors' from simulation results

Table 5.9. R&D investment and impact on poverty and output growth under output maximization when poverty line is $2.00/day

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	1,444	526	-128.3	0.92
- East Africa	287	562	203	-34.9	0.62
- Southern Africa	88	124	21	-3.7	0.58
-West Coast Africa	139	389	235	-79.4	1.34
-Sahel Africa	94	147	50	-7.8	0.53
South Africa	164	222	17	-2.5	0.51
W.Asia & N.Africa	546	884	41	-8.8	0.78
Asia	2,864	8,515	1,979	-456.3	2.28
E & SE Asia	1,956	5,305	700	-180.4	2.13
-China	1,457	4,682	474	-119.0	2.57
South Asia	908	3,209	1,278	-275.9	1.73
-India	707	1,982	1,033	-229.2	1.92
Latin America	957	1,604	92	-3.2	1.05
Southern Cone	637	1,042	39	-1.3	1.02
Andean	174	322	47	-1.7	1.17
Mexico	146	241	6	-0.2	1.05
Total	5,139	12,446	2,638	-597	1.84

Source: Authors' from simulation result

Table 5.10. R&D investment and impact on poverty and output growth under poverty minimization when poverty line is $2.00/day.

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	3,102	526	-230.7	1.83
- East Africa	287	1,199	203	-80.1	1.61
- Southern Africa	88	169	21	-6.0	0.95
-West Coast Africa	139	1,199	235	-123.7	2.44
-Sahel Africa	94	304	50	-17.9	1.37
South Africa	164	231	17	-3.0	0.57
W.Asia & N.Africa	546	730	41	-6.2	0.52
Asia	2,864	7,577	1,979	-485.4	1.72
E & SE Asia	1,956	3,493	700	-144.4	2.64
-China	1,457	2,595	474	-69.3	1.29
South Asia	908	4,084	1,278	-341.1	1.45
-India	707	3,003	1,033	-298.4	2.52
Latin America	957	1,038	92	-1.6	0.53
Southern Cone	637	690	39	-0.7	0.52
Andean	174	189	47	-0.8	0.53
Mexico	146	158	6	-0.1	0.54
Total	5,139	12,446	2,638	-724	1.44

Source: Authors' from simulation results

Table 5.11. R&D investment and impact on poverty and output growth under business as usual when poverty line is $2.00 and regions with higher R&D efficiency

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	1,224	526	-118.7	0.81
- East Africa	287	532	203	-46.1	0.82
- Southern Africa	88	119	21	-4.9	0.80
-West Coast Africa	139	210	235	-53.0	0.81
-Sahel Africa	94	143	50	-10.9	0.81
South Africa	164	221	17	-3.9	0.80
W.Asia & N.Africa	546	722	41	-9.1	0.80
Asia	2,864	4,323	1,979	-289.8	1.28
E & SE Asia	1,956	2,502	700	-106.5	1.17
-China	1,457	2,200	474	-70.3	1.37
South Asia	908	1,821	1,278	-183.3	1.17
-India	707	1,068	1,033	-150.0	1.17
Latin America	957	1,037	92	-2.5	0.84
Southern Cone	637	690	39	-1.0	0.84
Andean	174	189	47	-1.3	0.84
Mexico	146	158	6	-0.2	0.84
Total	5,139	7,307	2,638	-420.1	1.13

Source: Authors' from simulation results

Table 5.12. R&D investment and impact on poverty with 0.5 percent growth in productivity when poverty line is $2.00 and regions have higher R&D efficiency

	R&D investment (mill.2005 $)		Number of poor (mill.)	Changes in the number of poor (mill.)	Agricultural productivity growth rate (%)
	2008	2020	2008	2008-2020	2008-2020
Sub-Saharan Africa	772	2,347	526	-194.3	1.31
- East Africa	287	949	203	-75.1	1.32
- Southern Africa	88	248	21	-8.0	1.30
-West Coast Africa	139	411	235	-86.9	1.31
-Sahel Africa	94	279	50	-18.0	1.31
South Africa	164	459	17	-6.4	1.30
W.Asia & N.Africa	546	1,516	41	-15.0	1.30
Asia	2,864	7,967	1,979	-416.2	1.78
E & SE Asia	1,956	4,969	700	-149.6	1.67
-China	1,457	4,019	474	-97.0	1.87
South Asia	908	2,999	1,278	-266.6	1.67
-India	707	1,985	1,033	-218.5	1.67
Latin America	957	2,398	92	-4.0	1.34
Southern Cone	637	1,595	39	-1.7	1.34
Andean	174	436	47	-2.0	1.34
Mexico	146	366	6	-0.3	1.34
Total	5,139	14,228	2,638	-630	1.63

Source: Authors' from simulation results

Appendix: R & D and poverty elasticities in the literature

Effects of R & D investment on agricultural production: previous studies

Source	Country/Region	Elasticity Estimate		Years Covered
Lusigi, A. & Thirtle, C. 1997.	47 African Countries	Elasticity of agricultural growth (TFP) with respect to R&D expenditure	**0.031**	1961-1991
Thirtle, C., D. Harley, and R. Townsend. 1995.	22 African Countries	Elasticity of output wrt R& D Expenditures	**0.015**	1971-1986
Alene, A.A. and O. Coulibaly (2009)	27 Sub-Saharan African countries	Elasticity of agricultural productivity wrt agricultural research	**0.38**	1980-2003
Craig, B. J. et al . 1997.	67 developing countries	Elasticity of labor productivity wrt R & D expenditures	**0.093**	1961-1990

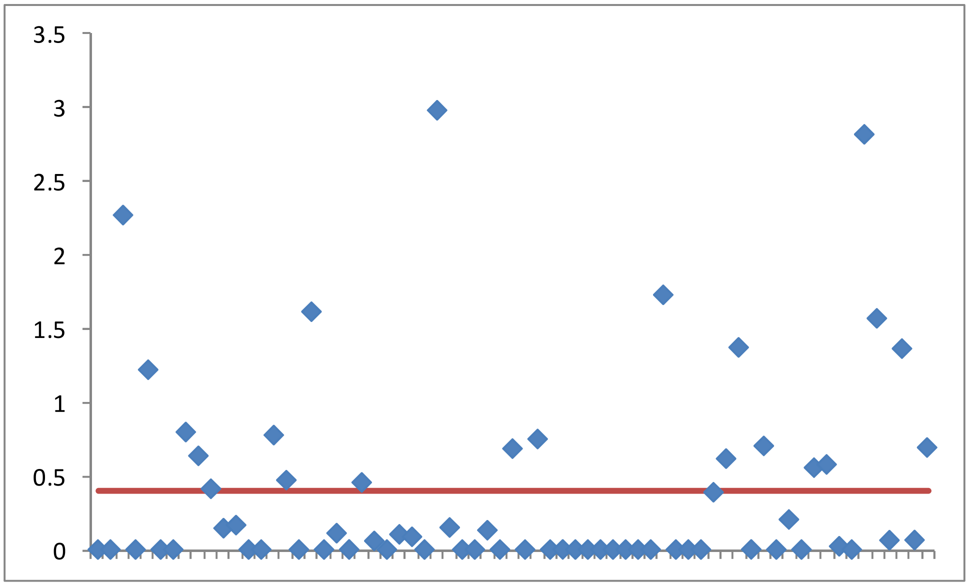
Effects of R & D investment on agricultural production: previous studies (continued)

Source	**Country/Region**	**Elasticity Estimate**		**Years covered**
Everson, Pray & Rosegrant (1998), Agricultural Research and Productivity Growth in India, Research Report 109, IFPRI	India	Elasticity of marginal total factor productivity w.r.t research expenditure	**0.045**	1956-1987
Fan&Pardey (1998) Govt Spending on Asian Agriculture:Trends&Production Consequences in 'Agricultural Public Finance Policy in Asia', APO	Asia	Elasticity of R&D expenditure w.r.t. output	**0.1706**	1972-1993
Fan (2000) Research Investment and the Economic Returns to Chinese Agricultural Research, Journal of Productivity Analysis, 14, 163-182	China	Elasticity of R&D expenditure w.r.t. output (variable coefft model)	**0.253**	1975-1997
		Elasticity of R&D expenditure w.r.t. output (fixed coefft model)	**0.151**	1975-1998
Fan & Pardey (1997) Research, Productivity, and output growth in Chinese agriculture, Journal of Development Economics, Vol 53, 115-137	China	Elasticity of R&D expenditure w.r.t. output (with time trend)	**0.101**	1965-93
		Elasticity of R&D expenditure w.r.t. output (with time trend)	**0.094**	
		Elasticity of R&D expenditure w.r.t. output (two way fixed effects model)	**0.21**	

Effects of agricultural output growth on poverty: previous studies

Article	Country/Region	Elasticity		Years Covered
Alene, A.A. and O. Coulibaly (2009)	27 Sub-Saharan African countries	Elasticity of poverty wrt to agricultural productivity	**-0.58**	1980-2003
Fan, S., X. Zhang, and N. Rao. 2004.	Uganda	Elasticity of poverty wrt growth in agricultural production	**-0.27**	1992;1995;1999
Thirtle, C. and J. Piesse. 2003.	44 African countries	Elasticity of poverty wrt agricultural productivity	**-0.717**	1980s,1990, 2000
Majid, M. 2004.	52 low and medium income countries	Elasticity of poverty wrt TFP (Using Sala-iMartin $1 poverty)	**-0.412**	Pooled 1970-2000
	52 low and medium income countries	Elasticity of poverty wrt to TFP (Using ILO $1 poverty)	**-5.24**	Pooled 1987-2000
Fan, Hazell&Thorat (1999), Linkages between govt spending, growth and poverty in rural India, Research Report 110, IFPRI	India	Elasticity of R&D expenditure w.r.t. Poverty	-0.065	1970-1995
Alene, A.A. and O. Coulibaly (2009)	27 Sub-Saharan African countries	Elasticity of poverty wrt agricultural productivity	-0.58	1980-2003
		Elasticity of poverty wrt agricultural research	-0.22	1980-2003
Thirtle, Lin&Piesse (2003) The Impact of Research-Led Agricultural Productivity Growth on Poverty Reduction in Africa, Asia and Latin America, World Development, Vol 31, 12,	22 African countries	Elasticity of poverty w.r.t. R&D	-0.26	
	11 Asian countries		-0.165	
	15 American countries		-0.03	
	All countries		-0.119	

Figure A1. Average value of the rate of growth (%) of technical change between 1997 and 2006 in 67 developing countries (points) and total average for the group of countries (line).



Source: Nin-Pratt and Yu (2009)