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PSYCHOLOGY AND DEVELOPMENT: THEORY AND EXPERIMENTAL EVIDENCE †

How High Are Rates of Return to Fertilizer? Evidence from Field Experiments in Kenya

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The idea that peasant farmers are rational profit maximizers has been a staple of development economics since Theodore Schultz (1964). It has also been influential in shaping policy. For example, agricultural experts have stressed the importance of fertilizer use in raising agricultural yields, pointing to impressive results on experimental farms and to huge differences in agricultural productivity across countries with different levels of fertilizer use (Robert Evenson and Douglas Gollin 2003). Historically, many countries subsidized fertilizer in response. But economists have been skeptical of claims that farmers are leaving money on the table, noting that fertilizer may not have the same returns on real-world farms as on experimental farms, that returns to fertilizer may be low for many farmers, even if they are high on average (Tavneet Suri 2007), that fertilizer may require complementary inputs, or may be risky. Many countries have withdrawn or scaled back fertilizer subsidies, in part because of fiscal constraints, corruption, and inefficiency in the administration of fertilizer subsidies, but also because of a belief among economists that farmers would choose to use inputs that actually raised profits in real-world conditions. Yet critics have charged that the withdrawal of subsidies has led to massive declines in agricultural output, and in some recent cases fertilizer subsidies have been restored (Celia Dugger 2007).

Behavioral economists have identified major departures from economists' standard models among consumers in the developed world, and development economists are increasingly finding similar effects in the developing world (see e.g., Nava Ashraf, Dean Karlan, and Wesley Yin 2006). However, it is still unclear whether these departures have any major impact on production. Fertilizer offers an attractive context to explore this question. Because it can be purchased in small quantities and used on small plots of land, and because farmers in the area we study are familiar with fertilizer, which has long been used in the area, it is possible to vary fertilizer use experimentally on real-world farms and to measure the impact on the use of potentially complementary inputs and on output, thus determining whether it has at least the potential to be profitable in real-world conditions.

The Kenyan Ministry of Agriculture recommends the use of hybrid seed and fertilizer for maize, the staple crop in most of Eastern and Southern Africa. This recommendation is based on evidence from experimental farms that fertilizer and hybrid seeds increase yield from 40 percent to 100 percent (see, for instance, Kenyan Agricultural Research Institute 1993; Daniel Karanja 1996). However, only about 60 percent of Kenyan farmers used fertilizer and hybrid seed in 2004 (Suri 2007), and in

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our sample (from a fairly poor district), only 37.0 percent of farmers reported ever using fertilizer and 35.7 percent reported ever using hybrid seeds. Even fewer had used fertilizer or hybrid seeds in the year prior to the survey: 23.9 percent and 17.2 percent, respectively. Like Suri (2007), we find that many farmers switch back and forth between using and not using fertilizer from season to season. The literature on technology adoption suggests many different explanations for low fertilizer usage, several of which we explore in a series of randomized field experiments in related research (Duflo, Kremer, and Robinson 2007). In this paper, we use a series of field trials on Kenyan farms to explore the most natural hypothesis: the possibility that, while fertilizer and hybrid seed increase yield on model farms, they are actually not profitable on many small farms, where conditions are less than optimal.

Our mean estimates of yield increases due to fertilizer use are in the range of the estimates found on model farms. We find that the mean rate of return to using the most profitable quantity of fertilizer we examined was 36 percent over a season, or 69.5 percent on an annualized basis. However, other levels of fertilizer use, including the combination of fertilizer plus hybrid seed recommended by the Ministry of Agriculture, are not profitable for farmers in our sample.

I. Research Design

Beginning in July 2000, a series of six field trials over three years were designed to ascertain the profitability of fertilizer on farms in Busia District, a relatively poor rural district in Western Kenya.[1] The project was implemented by International Child Support (ICS), a Dutch nongovernmental organization. Farmers were randomly selected from lists of parents of students enrolled at local schools.[2] On each farm, an ICS field officer measured 3 adjacent 30-square-meter plots (this is a very small fraction of the acreage typically devoted to maize, which is close to one acre, on average).

In the first few trials, one plot was randomly assigned to receive Calcium Ammonium Nitrate (CAN) fertilizer to be applied as top dressing (when maize plants were knee high). On the second plot, the full package recommended by the Ministry of Agriculture was implemented, hybrid seeds were used in place of traditional varieties, and Di-Ammonium Phosphate (DAP) fertilizer was supplied for planting along with CAN for use at top dressing. The third plot was a comparison plot on which farmers farmed as usual with traditional seed and without fertilizer.

ICS paid for the cost of the extra inputs (fertilizer and hybrid seed) and ICS field workers applied fertilizer and seeds with the farmers, followed the farmers throughout the growing season, assisted them with the harvest, and weighed the maize yield from each plot. Aside from these visits, the farmers were instructed to farm their plots just as they otherwise would have. Interviews with the farmers and field observation suggest that they did so. At the end of a growing season, the maize was harvested and weighed with the farmer. We compute the weight of dry maize obtained on each plot by multiplying the weight of wet maize by the ratio of the weight of dry to wet maize (obtained in the later field trials).

The program was continued for a total of six growing seasons, with small differences from season to season. In particular, only the first two field trials experimented with the official package recommended by the Ministry. We also varied the quantity of fertilizer applied. Several official sources, including the Kenyan Ministry of Agriculture and the Kenya Agricultural Research Institute (KARI), recommend one teaspoon per planting hole. Other extension agents recommend using ½ teaspoon, and many farmers use far less than the recommended amount (B.D.S. Salasya et al. 1998). To investigate this issue, farmers in several field trials experimented simultaneously with 1 teaspoon, ½ teaspoon, and ¼ teaspoon of top dressing fertilizer.

[1] Western Kenya has two growing seasons each year: the short rains season lasts from July or August until December or January, and the long rains season, which is the primary growing season, lasts from March or April until July or August.

[2] This sampling strategy was adopted because comprehensive lists of households in the area were not available. Since fertility and primary school enrollment rates in this area are both high, this should represent a large fraction of farmers in the area, although it underweights the elderly, the young, and those whose children are not in school.

Table 1—Returns to Fertilizer

	Mean (1)	Median (2)	Std. error (3)	Obs. (4)
Panel A. ¼ Teaspoon Top Dressing Fertilizer				
Percentage increase in yield	28.1	8.9	6.8	112
Rate of return over the season	4.8	−27.7	38.8	112
Annualized rate of return (at the mean and median)	8.4	−42.6		112
Panel B. ½ Teaspoon Top Dressing Fertilizer				
Percentage increase in yield	47.6	24.3	6.1	200
Rate of return over the season	36.0	23.9	16.9	202
Annualized rate of return (at the mean and median)	69.5	44.4		202
Panel C. 1 Teaspoon Top Dressing Fertilizer				
Percentage increase in yield	63.1	30.6	8.2	273
Rate of return over the season	−10.8	−16.9	8.4	274
Annualized rate of return (at the mean and median)	−17.8	−27.3		274
Panel D. Full Package Recommended by Ministry of Agriculture				
Percentage increase in yield	90.6	48.7	15.4	82
Rate of return over the season	−38.9	−49.4	10.4	85
Annualized rate of return (at the mean and median)	−48.2	−59.7		85

Notes: See text for description of rate-of-return calculation. The rates of return are annualized at the mean and median raw return. The official package recommended by the Ministry of Agriculture includes planting fertilizer, fertilizer at top dressing, and hybrid seeds.

II. Results

A. *Mean and Median Estimates of Returns*

Table 1 presents the mean, median, and standard deviation of the increase in yield, and the rate of return obtained by each farmer. The percentage rate of return over the season is defined as 100 * [(value of treatment plot output − value of comparison plot output − value of input) / value of input] − 100.[3] Note that the term "input" in this calculation should include any extra cost to the farmer in terms of extra labor, weeding, and other costs. In several field trials, however, field officers asked farmers the number of hours spent weeding or otherwise tending the plot, and recorded the physical appearance of the plot at various visits. There were no differences between the treatment and control plots in the time that farmers reported that they spent weeding, or in field officers' observations of how much weeding had been done on each plot. The time associated with applying fertilizer and with harvesting extra output is likely small, and no other inputs are used. For this reason, it seems reasonable to assume that costs other than fertilizer were similar between treatment and control plots.

An important input in this exercise is the price used in valuing maize production. The price of maize is very low at the beginning of the season and much higher at the end, when maize is rarer. Most farmers in our sample are net maize buyers, buying maize at the end of the season after their own stock runs out. We therefore price maize at the price it reaches just before the next season's harvest: 40 Kenyan shillings (or $1.2 dollars at PPP) per goro-goro (approximately 2 kilograms), for the short rains harvest and 25 Kenyan shillings (Ksh) per goro-goro for the long rains harvest.[4] The results are pooled across seasons (results separated by season are available in the working paper version).

Annualized returns adjust for the fact that money is invested in inputs several months before marginal maize is consumed (it is approximately nine months from planting and seven months from the application of top dressing until the peak price is reached the next season). In Table 1,

[3] Extreme outliers in the profit calculations are removed from this calculation.

[4] The return to fertilizer should be seen as the return to using fertilizer and holding the excess production until the rest of the harvest runs out. Returns would be lower if farmers sold immediately after harvest.

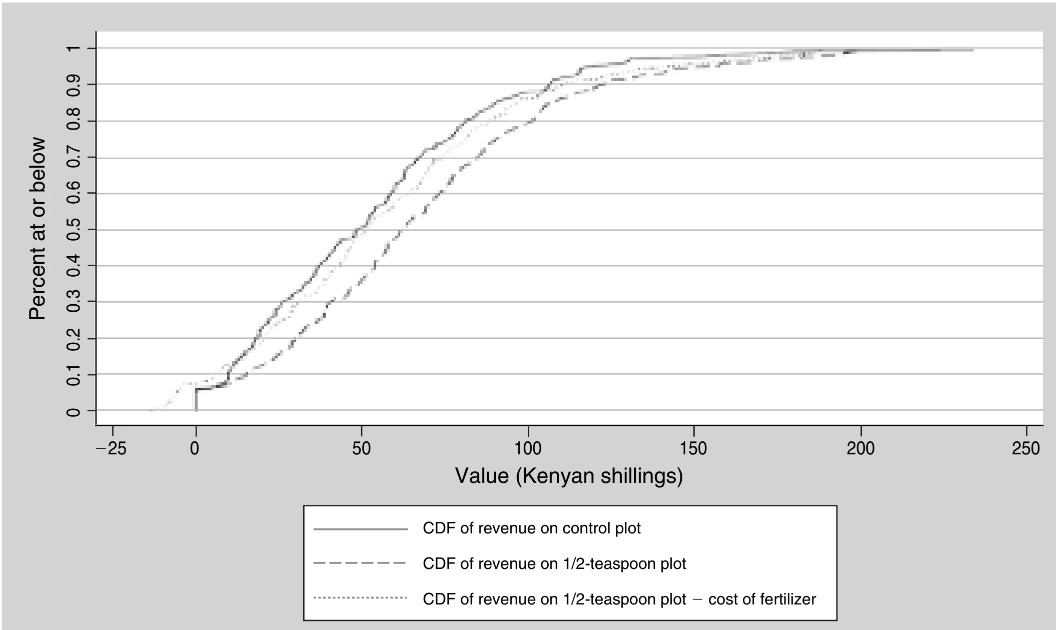

Figure 1. CDF of Revenue on Control and ½ Teaspoon Plots (30 Square Meters)

we report the annualized value of the mean and median seasonal rates of return, rather than the mean and median annualized returns.[5]

The increases in yield are generally consistent with the results obtained in experimental farm trials: using ¼, ½, and 1 teaspoon of fertilizer increases yield by 28 percent, 48 percent, and 63 percent, respectively. The full package recommended by the Ministry of Agriculture increases yield by 91 percent, on average. While the median increase in yield remains high, it is significantly lower than the mean (9 percent, 24 percent, 31 percent, and 49 percent, respectively).

Rate-of-return calculations suggest that ½ teaspoon of fertilizer yields a mean raw return of 36.0 percent, which corresponds to an annualized mean return of 69.5 percent. However, the seasonal rates of return to ¼ teaspoon and 1 teaspoon (the KARI recommendation) are 4.8 percent and −10.8 percent, respectively. Moreover, the full package recommended by the Ministry of Agriculture is highly unprofitable, on average, for the farmers in our sample (although it may be profitable for farmers who are able to provide other complementary inputs).

Thus, while fertilizer can be very profitable when used correctly, one reason why farmers may not use fertilizer and hybrid seeds is that the official recommendations are not adapted to many farmers in the region. This also suggests that fertilizer is not necessarily easy to use correctly, which implies that it may not be profitable for many farmers who do not use the right quantity. This also means that there is substantial scope for learning, an issue we explore in our related work.

B. *Risk and Heterogeneity*

The return to fertilizer use is thus sensitive to how it is used. It is also important to assess whether returns vary across farmers and season. Figure 1 shows the CDF of the value of the yield on the treatment and comparison crop, and the value of the yield after the cost of fertilizer has been subtracted (net revenue). While the distribution of yield on the fertilized plot stochastically

[5] We report the annualized mean rather than the mean of the annualized returns because annualized returns are a convex function of seasonal returns and seasonal returns are positive on average, so that symmetric measurement error will lead annualized returns to be overstated.

TABLE 2—CROSS-SECTIONAL RELATIONSHIP BETWEEN RETURNS TO TOP DRESSING AND BASE RETURNS

	(1)	(2)	(3)	(4)
Weight of maize on control plot			−0.028	−0.188
			(0.039)	(0.124)
Indicator for long rains season			−2.479	
			(1.506)	
Education	0.019	−0.275	0.01	
	(0.071)	(0.370)	(0.071)	
Income in past month (in 1,000 Kenyan shillings)	0.000	0.102	0.002	
	(0.066)	(0.261)	(0.066)	
Household had ever used fertilizer before	0.578	5.984	0.591	
	(0.545)	(3.020)*	(0.543)	
House has mud walls	0.353	4.400	0.308	
	(0.802)	(4.097)	(0.801)	
Acres of land owned	−0.005	0.027	−0.010	
	(0.045)	(0.170)	(0.045)	
Rate of return in previous demonstration		−0.312		
		(0.820)		
School controls	YES	YES	YES	NO
Individual fixed effects	NO	NO	NO	YES
Observations	323	59	323	122
p-value for joint significance of school controls	0.16	0.04	0.10	
R-squared	0.08	0.23	0.09	0.04

Notes: The dependent variable is the return to ½ teaspoon top dressing fertilizer, for those farmers who used ½ teaspoon. For the remaining farmers, the dependent variable is the return to 1 teaspoon top dressing fertilizer. The weight of maize on the control plot is the wet weight, before drying and shelling. Regressions also include controls for whether the farmer had previously participated in a demonstration trial, and indicators for having a thatch roof and a mud floor. Columns 2 and 4 only include the 61 farmers that took part in 2 trials. Standard errors in parentheses.

* Significant at 10 percent level.
** Significant at 5 percent level.
*** Significant at 1 percent level.

dominates that on the nonfertilizer plot, the distribution of the net revenue does not: the CDFs cross around the percentile 13.5 percent. This suggests that there are either some farmers or some seasons where fertilizer is not appropriate, though it still appears that using fertilizer yields higher profits in the vast majority of cases.

There could, however, be heterogeneity in the returns across farms. To assess the extent of heterogeneity in expected returns, column 1 in Table 2 presents regressions of farmers' measured rate of return on observable characteristics.[6] None of the individual variables is significant, except geographic fixed effects, and the R-squared of this regression is only 8 percent. Surprisingly, even education and past experience with fertilizer use do not seem to be correlated with returns. Furthermore, when we include (in column 2) the rate of return experienced by the same farmer in a previous trial (61 farmers participated in two trials, 59 of whom can be included in this regression), the coefficient on the past season's return is negative and insignificant. We thus find little evidence for substantial heterogeneity in rates of return to fertilizer across plots.

The standard deviation of revenue net of input cost is 39 Ksh on the control plot, and 42 Ksh on the treatment plot, suggesting a small increase in risk (since we saw little evidence of substantial unobserved heterogeneity). There is, however, little prima facie evidence that returns to fertilizer have a high "beta" in the sense of being correlated with other risks faced by farmers. The partial correlation between the rate of return to fertilizer and the base yield in the control plot is actually negative: the returns to fertilizer are smaller when the control plot does better (see Table 2, column 3). Furthermore, a fixed-effects regression of the returns to fertilizer on the weight of maize on the control plot

[6] Note that our measure of the rates of return on any one farm is very noisy, since we are differencing two noisy random variables which are measured on very small plots.

for the 61 farmers who participated in two demonstration trials actually yields a statistically insignificant negative coefficient (Table 2, column 4).[7] Since returns with fertilizer are only slightly riskier than without fertilizer, mean returns are high, and returns are not highly correlated with other risks farmers are exposed to, it appears that using at least a small amount of fertilizer would yield high expected returns with little added risk to farmers' consumption (fertilizer can be purchased in quantities as small as one kilogram at a cost of about 30 Ksh.). Risk aversion, thus, seems unlikely to explain why farmers do not use at least some fertilizer.

C. *Is It Worth the Effort? How Much Can Fertilizer Increase Income?*

It is possible that even if returns are high, the absolute income gain from using fertilizer does not make it worthwhile if there are significant fixed costs in using fertilizer. For instance, these costs may include time and money spent traveling to market, time spent learning how to use fertilizer, and psychic costs of changing habits (Abhijit Banerjee and Duflo 2007). The absolute income gains to fertilizer are reasonably substantial, however. The average acreage under maize cultivation for all farmers in our area is 0.93 acres. Without fertilizer or hybrid seed, this would produce about 8,000 Ksh (or $242 PPP) worth of maize on average. Using ½ teaspoon of top dressing fertilizer per hole would increase agricultural income (net of fertilizer cost) by about 1,100 Ksh ($33 PPP). This represents a 15 percent increase in net income and more than a month's agricultural wages. The fixed cost of using fertilizer alone is therefore unlikely to be the whole story, as long as farmers are able to use fertilizer on their entire plot. It may, however, still play an important role in cases in which the farmer's optimal use would be less than the full plot (for example because of financing constraints).

III. Conclusion

A series of demonstration plot experiments in which treatment and control plots were randomly allocated within farms suggests that top dressing fertilizer, when used in appropriate quantities, is highly profitable, with mean returns of 36 percent over a season, and 69.5 percent annualized. However, other levels of fertilizer use, including the official recommendations of the Ministry of Agriculture, are unprofitable for the average farmer in our sample.

In current work (Duflo, Kremer, and Robinson 2007), we investigate two reasons for low adoption of fertilizer: lack of information and savings difficulties. Our findings suggest that simple interventions that affect neither the cost of, nor the payoff to, fertilizer can substantially increase fertilizer use. In particular, offering farmers the option to buy fertilizer (at the full market price, but with free delivery) immediately after the harvest leads to an increase of at least 33 percent in the proportion of farmers using fertilizer, an effect comparable to that of a 50 percent reduction in the price of fertilizer (in contrast, there is no impact on fertilizer adoption of offering free delivery at the time fertilizer is actually needed for top dressing). This finding seems inconsistent with the idea that low adoption is due to low returns or credit constraints, and suggests there may be a role for non–fully rational behavior in explaining production decisions. Our findings also contribute to the growing body of evidence suggesting that returns to capital in developing countries are often high (Banerjee and Duflo 2005).

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[7] Note, however, that uncorrelated measurement errors in plot yield will tend to bias this coefficient downward, since the yield on the control plot enters negatively in the rate-of-returns calculation.

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