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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 boosting 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 or that these returns may vary and be low for many farmers even if they are high on average (Tavneet Suri, 2007); or they may require complimentary inputs, or have risky and variables results. Many countries have withdrawn or scaled back fertilizer subsidies - in part because of fiscal constraints and corruption and inefficiency in the administration of fertilizer subsidies - but also in part because of a belief among economists that farmers would 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).

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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 measure the impact on 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, based on evidence from experimental farms that fertilizer and hybrid increase yield from 40% to 100% (see, for instance, Kenyan Agricultural Research Institute (1993) and Daniel Karanja (1996)). However, only about 60% of Kenyan farmers used fertilizer and hybrid seed in 2004 (Suri, 2007), and in our sample (from a fairly poor district), only 37.0% of farmers reported ever using fertilizer and only 23.9% had used fertilizer in the year prior to the survey. 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 first order hypothesis: the possibility that, while fertilizer and hybrid seed increase yield in 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, implying a mean rate of return of 36% over a season, or 257% on an annualized basis. The combination of fertilizer plus hybrid seed recommended by the Ministry of Agriculture is not profitable 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. The project was implemented by International Child Support (ICS), a Dutch NGO. Farmers were randomly selected from lists of parents of students enrolled at local schools.[1] 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 1 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, hybrid seeds were used in place of traditional varieties and Di-Ammonium Phosphate (DAP) fertilizer was supplied for planting along with CAN for top dressing. This combination is the official package recommended by the Ministry of Agriculture. The third plot was a comparison plot on which farmers farmed as usual with traditional seed and

[1] This sampling strategy was adopted because comprehensive lists of households in this 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.

without fertilizer.

ICS paid for the cost of the extra inputs (fertilizer and hybrid seed) and ICS field workers applied fertilizer and seed 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 would have otherwise. 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 wet to dry 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),[2] recommend one teaspoon per planting hole.[3] Other extension agents recommend using ½ teaspoon , and many farmers use far less than the recommended amount (.BD.S. Salasya et al., 1998). To investigate this issue, farmers in several field trials experimented simultaneously with ½ teaspoon, 1 teaspoon, and ¼ teaspoon of top dressing fertilizer.

II. Results

A. Mean and Median Estimates of Returns

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[2] These are blanket recommendations made for all of Kenya, based on close to 1,000 field trials that were conducted throughout Kenya between 1966 and 1986 (KARI, 1987; KARI, 1992; KARI, 1994).

[3] Top dressing fertilizer is not actually put in the hole , but the hole is the unit of measurement, because farmers may plant several seeds per hole and may not space holes according to official guidelines.

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.[4] Note that this calculation ignores any extra cost (or gain) to the farmer in terms of labor, etc. In several field trials, 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 was no difference in the time spent weeding or harvesting on the plot that received treatment and no differences in the field officer's impression of how much weeding had been done on each plot. For this reason, it seems reasonable to assume that labor and other costs were similar between treatment and control plots.

Table 1: Returns to Fertilizer

	mean (1)	Median (2)	std. dev. (3)	Obs (4)
Panel A. 1/4 Teaspoon Top Dressing Fertilizer				
% Increase in Yield	28.1	8.9	71.7	112
Rate of Return Over the Season	4.8	-27.7	410.3	112
Annualized Rate of Return	338.1	-41.8	1861.2	112
Panel B. 1/2 Teaspoon Top Dressing Fertilizer				
% Increase in Yield	47.6	24.3	86.5	200
Rate of Return Over the Season	36.0	23.9	239.9	202
Annualized Rate of Return	257.6	44.4	797.2	202
Panel C. 1 Teaspoon Top Dressing Fertilizer				
% Increase in Yield	63.1	30.6	135.2	273
Rate of Return Over the Season	-10.8	-16.9	138.9	274
Annualized Rate of Return	68.4	-27.2	329.3	274
Panel D. Full Package Recommended by Ministry of Agriculture				
% Increase in Yield	90.6	48.7	139.1	82
Rate of Return Over the Season	-38.9	-49.4	96.0	85
Annualized Rate of Return	-29.8	-59.7	125.6	85

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

Notes: See text for description of rate of return calculation.
The official package that is recommended by the Ministry of Agriculture includes planting fertilizer, fertilizer at top dressing, and hybrid seeds.

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. Since most of our farmers end up being net maize buyers, and buy maize at the end of the season after their own stock runs out, we price maize at the price it reaches just before the next season's harvest. For the Short Rains harvest, this price is 40 Kenyan shillings (or $1.2 dollars at PPP) per goro-goro (approximately 2 kilograms), which is the average price of maize at the end of the Long Rains growing season. For the Long Rains harvest, this price is 25 shillings per goro-goro. The results are pooled across both 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 7 months from the application of top dressing until the peak price is reached the next season).[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%, 48%, and 63%, respectively. The full package recommended by the Ministry of Agriculture increased yield by 91% on average. While the median increase in yield remains high, it is significantly lower than the mean (9%, 24%, 31%, and 49% on average).

The rate of return calculations suggest that fertilizer usage is profitable on average and for the median farmers for all application quantities, but that returns are highest for ½

[5] There are large seasonal swings in maize prices, so the return to fertilizer should be seen as a 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.

teaspoon of fertilizer (a raw return of 36.0% and an annualized return of 258%). The raw rates of returns to ¼ teaspoon and 1 teaspoon are 4.8% and -10.8%, respectively. In contrast, despite the fact that it leads to the largest increase in yield, the full package recommended by the Ministry of Agriculture is actually unprofitable on average for the farmers in our sample (although it may be profitable for farmers who are able to provide other complementary inputs). The low adoption of the full package could thus be due to that fact that it is not profitable for most people in this region. The low adoption of fertilizer remains much more puzzling as it seems to be very profitable on average.

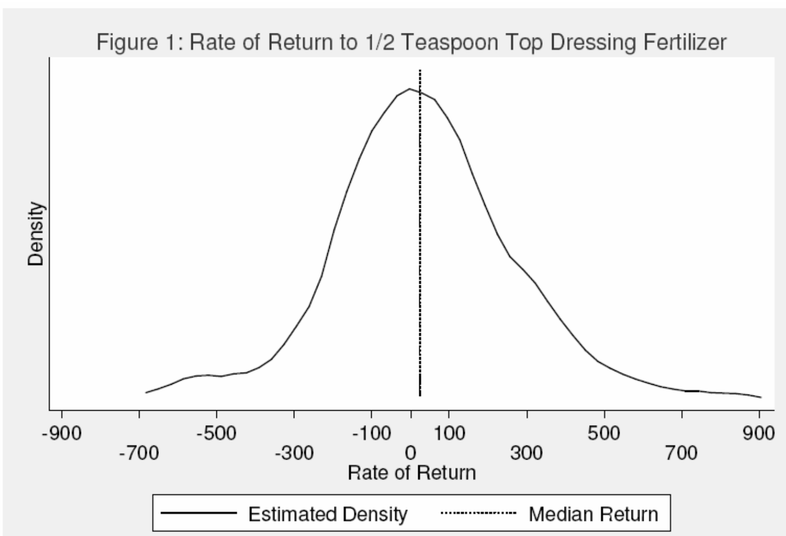
B. Risk and Heterogeneity

The standard deviation in these estimated rates of returns is, however, very large. For our preferred fertilizer choice (½ teaspoon of top dressing), the mean annualized rate of return is 258%, and its standard deviation is 797%. Note that random variation in yields across plots in a given season (as well as measurement error) will lead the measured standard deviation in rates of return to overestimate the actual standard deviation of the extra return due to using fertilizer on a particular plot. This effect is likely substantial since each plot was only 30 square meters, and calculating the rate of return to fertilizer requires differencing two random variables.[6] Even though the average returns are large, treatment yields exceed comparison yields by more than the cost of fertilizer only 56% of the time.

This variability could come from measurement error and random variation in yield across plots unrelated to fertilizer, from heterogeneity between farmers in expected rates of

[6] Note also that since annualized returns are a convex function of seasonal returns and seasonal returns are positive on average, symmetric measurement error may lead annualized returns to be overstated.

returns to fertilizer or from risk. 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 . None of the individual variables are significant, except geographic fixed effects, and the R-squared of this regression is only 8%. 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), the coefficient on the past season's return is negative and insignificant.



While this variability comes certainly in part from measurement error, the data are also consistent with the hypothesis that there is considerable risk associated with fertilizer use. This risk could discourage farmers from using large amounts of fertilizer. However, even risk averse farmers should want to use at least some fertilizer, unless the rate of return to fertilizer investment was strongly positively correlated over time with the overall yield of the plot. There is little evidence for such a high positive correlation: 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).[7] These estimates are cross-sectional and could be biased downwards by measurement error or idiosyncratic random variation in output on the comparison plot, but a fixed effects regression of the returns to fertilizer on the weight of maize on the control plot for the 61 farmers who participated in two demonstration trials yields a statistically insignificant negative coefficient (Table 2, column 4). Since fertilizer can be purchased in quantities as small as one kilogram, at a cost of about 30 Ksh,, risk aversion seems unlikely to explain why farmers do not use 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, time and money spent traveling to market, time spent learning how to use fertilizer, or 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 close to 200 goro-goros of maize, worth about 8,000 Kenyan shillings (or $242 PPP). Using ½ teaspoon of top dressing fertilizer per hole would cost approximately 1,200 shillings and increase agricultural income (net of fertilizer cost) by about 1,100 shillings ($33 PPP). This represents a 15% increase in net income and more than a month's agricultural wages. The fixed cost of using fertilizer alone is therefore unlikely to

[7]Note that to the extent that unobserved ability will both lead farmers to have higher yield on the control plot and higher rates of returns to using fertilizer, we would expect that the estimate would be an upwardly biased estimate of the extent to which correlated shocks drive both base yield and improvement from fertilizer use.

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 risk aversion or financing constraints).

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	0.000	0.102	0.002	
(in 1,000 Kenyan shillings)	(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 1/2 teaspoon top dressing fertilizer, for those farmers that used 1/2 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%; ** significant at 5%; *** significant at 1%

III. Conclusion

A series of demonstration plot experiments in which treatment and control plots were randomly allocated within farms suggests that top dressing fertilizer (especially if used in appropriate quantities)is highly profitable, with a 258% average annualized return and a mean non annualized return of 36%. We cannot rule out substantial variability in returns, but these mean returns are as high for farmers who had not used fertilizer before as for those who had providing no *prima facie* evidence that those who do not use fertilizer are those for whom returns are low (see also Suri, 2007). The package recommended by the Ministry of Agriculture (hybrid seed, fertilizer at planting, and fertilizer at top dressing) is not profitable for the farms in our sample.

In current work (Duflo, Kremer and Robinson, 2007), we investigate two reasons for low adoption: lack of information about fertilizer 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% in the proportion of farmers using fertilizer, an effect comparable to that of a 50% reduction in the price of fertilizer. This finding seems inconsistent with the idea that low adoption is due to low returns or credit constraints.

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