Understanding Technology Adoption: Fertilizer in Western Kenya
Preliminary Results from Field Experiments

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1. Introduction

In rural Western Kenya, the Ministry of Agriculture recommends the use of hybrid seeds and fertilizer to increase maize yields. This recommendation is based on evidence from experimental farms that fertilizer substantially increases yield. In 2000, however, according to a survey we conducted in a random sample of farmers, just 45% of farmers had ever used fertilizer, and just 15% had used fertilizer in the year before. This project seeks to understand why so many people do not use fertilizer even though it appears to have the potential to improve yields considerably, thus improving poor farmers' lives as well as improving food security in the country.

In this project, conducted in collaboration with International Christian Solidarity (ICS), a NGO working in Busia District in Western Kenya, and which began in the summer of 2000, we are using field trials to investigate several hypotheses of why farmers are not using fertilizer: Fertilizer is not profitable in the actual conditions in farmers' farms; it is profitable but farmers do not know how to use it, or how profitable it is; or, farmers have difficulty financing the investment, perhaps because of their inability to save.

In a series of randomized field experiments, we have explored (and continue to explore) these three hypotheses. Our main results suggest that: (1) fertilizer is profitable; (2) providing information goes part of the way towards increasing fertilizer adoption; but (3)

programs that help the farmers commit at the point where they have money to use fertilizer in the future have a very large impact on future fertilizer adoption. The effectiveness of this program is very sensitive to the strength of the commitment that each variant offers.

This note presents the results we have obtained so far, and the experiments that are currently in the field, and for which we expect results by the time of the conference.

2. Preliminary Results

A. Fertilizer is Profitable

We began a pilot project during the summer of 2000. A group of farmers was randomly selected among parents of schoolchildren in the area. We measured three adjacent 30 square meter plots for each farmer. We randomly selected one of these plots to apply fertilizer and hybrid seed, one of the plots to apply only fertilizer at "top-dressing" (when the plant is knee-high), and one of the plots to be a comparison plot. We applied the fertilizer with the farmers themselves, followed these farmers throughout the growing season, harvested with them, and weighed the maize yield from each plot. Otherwise, the farmers were instructed to farm their plots as they would otherwise have.

We continued this same program for the next four growing seasons, with small differences from season to season: After the second pilot, we stopped using hybrid seeds, because it was too difficult to time our work with the farmers properly. The quantity of fertilizer used in each hole varied from season to season as well, and one pilot used all three quantities. In total, six "pilot" projects were conducted over three years, since Kenya has two growing seasons per year. The profitability of fertilizer was measured each season. Calculating profitability is not quite as straightforward as it might seem, however, for 2 reasons. First, after maize is harvested, it must be dried, shelled, and then dried further after shelling before it may be sold in market, so it's necessary to estimate the amount of wet lost in the drying and shelling process, which we were only able to

estimate accurately starting with Pilot IV.[1] We now use the data generated in pilot IV to estimate profitability in previous years.

The second issue is that the price of maize varies considerably over the course of the year. As would be expected, the price reaches a minimum immediately after the harvest, so using the post-harvest price would make it much more difficult to make a profit. In the analysis that follows, we have calculated the profit using 2 prices: the 2003 short rains post-harvest price of 25 Ksh per goro-goro (the Busia market price on February 1, 2003), and 40 Ksh per goro-goro (the price on June 1, 2003, a few months before the next long rains harvest).[2]

Table 1 presents the calculation of rates of returns over the four months of the growing season. This is simply calculated as: (yield treatment plot - yield control plot)/cost of treatment. We make no adjustment for labor cost since our surveys do not suggest that farmers used either less or more labor on the fertilized plots than on the non-fertilizer plots (for weeding, for example). These rates of returns are not used.

The rate of return varies by season, and is sensitive to how much fertilizer is used, and our calculations are obviously sensitive to the price at which we value maize. but fertilizer at top dressing appears to be quite a good investment, especially when small quantities (half a teaspoon per hole) are used. Using the 40 ksh per goro-goro price, the average rate of return to a 8 months investment varies between 28% (for a teaspoon of fertilizer) to 134% (for half a teaspoon of fertilizer).

It therefore appears that fertilizer is a profitable investment, even given the actual conditions on the farmers' farms. However, it appears that the official package recommended by the Ministry of Agriculture (fertilizer plus top dressing) is actually

[1] We employed the following method in Pilots IV-VI. After harvesting, we painted the bottom of the maize cobs a different color for each plot, weighed the output on each plot, and counted the number of cobs of each color. We returned in about a week to shell the maize and weigh the kernels. As a compliance incentive, the farmer was given an agricultural tool as a gift if the number of cobs left after a week matched the original number. Though the process sounds a bit complicated, nearly all farmers were able to comply. Using this data, we estimate a drying and shelling ratio of 0.55.

[2] A goro-goro is the standard unit for buying and selling maize in Western Kenya. A goro-goro is a volume measure equivalent to roughly 2.25 kg of dry maize kernels.

more risky, and less profitable on average, than the use of fertilizer only for top dressing. Moreover, there is some confusion in the recommendations about how much fertilizer should be used, and it appears that the average return is highest for the smaller quantity of fertilizer. This confusion implies that this remains an environment where learning is probably very important.

B. Learning

This setup is ideal to test the proposition that lack of information about either the rate of return to fertilizer, or its proper use, discouraged the farmers from using fertilizer: Since the farmers participating in each pilot were randomly selected from the parents of a school list, participating in the trials is randomly assigned within a school, and parents from the same schools that were not selected form the control group.

The trials can be thought of as a particularly intense form of agricultural extension. After the harvest, we also discussed the results of the experiment in detail with each farmer, and helped him worked through a calculation of costs and benefits of using fertilizer, using his own data as well as the data for all the farmers who participated in the trials. If the farmers lacked information either about costs or about the proper way to use fertilizer, this intervention should have provided that to them.

After each pilot, we have been following each farmer to see if he chose to use fertilizer on his own in the subsequent seasons. Table 2 presents the results. Column (1) suggests that participants in the pilot program increased their participation in the next season by 17 percentage points, from a basis of 20% in the control group. Over time the effect declined somewhat (to 9% in the next season, and 10% three season later). The precision of these results decline, however, since the number of observations decline. This suggests a non-trivial impact of agricultural extension, although less than half of the farmers in the treatment group adopted fertilizer. Table 3 is a first exploration of the determinants of fertilizer adoption. There is a small positive impact of higher rate of returns of the experimental plot on the probability to adopt fertilizer in the future,

although this must be taken with some caution, as the rate of return is not randomly assigned.

Several other comparisons were set up to understand better the channels by which learning takes place. First, we studied diffusion, by following both the neighbors (geographical network) and the people named as agricultural contacts (actual network) of the pilot and the comparison farmers. Diffusion of agricultural technology has been studied before (Foster and Rosenzweig [1995], Munshi [1998] Udry and Conley [2000]), but this setup allows us to provide experimental evidence that does not suffer from omitted variable or simultaneity bias. Table 4 shows the results for agricultural contacts (panel A) and neighbors (panel B). In each of these panels, we compare the friends (or the neighbors) of the pilot farmers with the friends (or the neighbors) of the comparison farmers. Panel A shows no evidence of the diffusion of the use of fertilizer: The difference between the friends of the pilot farmers and the friends of the comparison farmers is 7% for fertilizer, and very close to 0% for fertilizer or seeds. Panel B's result is even more surprising: There seems to be a negative and significant impact of being the neighbor of a pilot farmer on the probability for adopting fertilizer.

The pilot program combines several interventions: A demonstration of the technique and a chance for the farmer to experiment for himself. We also very clearly demonstrated to farmers that the NGO was endorsing fertilizer use. Three interventions "unpack" these three aspects.

First, we invited randomly selected friends of the farmers in Pilots 2 and 3 to attend key periods of the demonstrations. The results are presented in table 5. In the first four columns, we present the contrast between invited friends and the friends of the comparison farmers. The results are impressive: Attending the demonstrations seems to be as effective as being the main farmer for the trials. The difference between the adoption of the friends who were invited to the trials and the friends of the comparison farmers is 17%, about as large as the effect in table 2. The effect persists in the next season as well. Columns 5 to 8 present the contrast between invited friends and uninvited

friends of the pilot farmers. Not surprisingly, given the results in tables 4 and 5, there is a sizeable difference between adoption in the two groups.

Second, we distributed to randomly selected farmers in other schools small quantity of seeds and fertilizer (a "starter kit" of these inputs). We explained to them how to use the inputs, but did not actually monitor them or measure the yields on each plot. We then followed up fertilizer adoption in the next season. The result is shown in table 6. The "starter kit" program also has significant impact of the adoption of agricultural inputs: The difference between participants and non-participants is only 7% for fertilizer, but 12% for fertilizer or seed, which suggest that the opportunity to try out fertilizer and seeds does indeed influence future adoption.

Finally, we tried to evaluate whether the only effect of this program is to convince the farmers that an NGO that is active in their area wants them to use fertilizer. This may lead them to either start using fertilizer (even if the interventions themselves do not teach them anything specific) or to start pretending that they are using it. To test this hypothesis, we visited a randomly selected group of farmers, and we delivered a speech "endorsing" fertilizer use. Namely, we simply said that the government recommended the use of fertilizer, and that we had been conducting trials in the area, with good results. We did not provide any more detail. In the next season, we followed up adoption by these farmers, compared to comparison farmers. The results are shown in columns 3 and 4 of table 5. The endorsement seems to have a modest positive, but insignificant, impact: The impact of the probability of adopting fertilizer is 5%, and to increase the probability of adopting fertilizer and seeds is 8%. These impacts are significantly smaller than the impact of participating in the trials, or being invited to a demonstration.

[MODEL GOES HERE]

C. Savings and Commitment Devices

These results suggest that knowledge both about how to use fertilizer and the returns to fertilizer are a factor in future adoption. However, even after participating in the experiment, more than half the farmers do not use fertilizer. Moreover, many stop after a season. A reason may be that farmers are still an undesirable investment, perhaps because of the risk associated to using them. Another possible explanation, more consistent with the fact that, after the pilot, most farmers plans to use fertilizer, but only a few actually carry out the plan, is that farmers are unable to save the money they need to buy fertilizer, despite their desire to do so. This suggests that a savings mechanism in which to hold their money could help them invest in agricultural inputs. To explore this issue, we set up the Savings and Fertilizer Initiative (SAFI), a program which provides a commitment device for those farmers who wanted to use fertilizer in 2001.

The main idea behind the SAFI program is that farmers would like to use fertilizer, but do not have the money on hand at the time of planting or top dressing. The general principle of the SAFI program is that the farmer is visited right after harvest (when maize and, potentially, money is relatively plentiful), and is offered the option of purchasing a voucher for fertilizer. ICS then delivers the fertilizer at the time of planting. The program is therefore a commitment device, akin to a 401(k) program. We have tried out several variants of the program, initially by trial and error, and as we analyzed the results and form theories, by introducing variation that allow us to distinguish the role of the commitment device from other services the program may offer, as well as trying to understand the nature of the commitment that is beneficial to the farmers. Table 7 presents the take up of various versions of the program.

In the first version of the program (SAFI 2), a group of farmers were randomly selected, and visited right after harvest. They were visited twice, once to ask them whether they wanted to participate in the program, and one other time, a few days later, to collect the money. Forty-four percent of the farmers expressed interest, and 15% eventually purchased fertilizer. As has been argued with 401(k) , this could be pure substitution, in the sense that farmers who were planning to use fertilizer anyway ordered fertilizer from us for the convenience of having it delivered, or because they thought they were getting a

better price. To assess the extent to which this happened, we monitored fertilizer adoption by these farmers in that season and the following one. Table 8 presents the result. The effect on fertilizer adoption is not statistically different than the effect on take up (the point estimate is even a bit larger). It therefore does not seem that farmers who were planning to use fertilizer anyway purchased it from us: the SAFI adopters appear to be people who would not have used fertilizer otherwise. Of course, we do not have evidence on whether farmers save less in other forms as a result. It could also be the case that the marginal farmers were convinced by the reduction in the transportation cost, a point to which we come back below.

In the subsequent versions of the program (SAFI 3, 4, 5 and 6), we combined SAFI with the demonstration program: In SAFI 3, a subsample of the pilot farmers were asked whether they wanted to use some of the maize that they had just harvested to purchase fertilizer. They had to give us the money right away, so that they had no chance to procrastinate. Among those who were offered SAFI 3 or 4, 80% of farmers did indeed purchase fertilizer. However, SAFI 3 was offered only to 10 farmers randomly selected amongst twenty who had done well in the experiments: farmers were allowed to buy fertilizer only with the extra maize that they got on the top dressing plot. To make calculations easier, farmers were only allowed to sell us either 4 kilograms or 8 kilograms of maize, in exchange for either 1 kilogram or ½ kilogram of top dressing fertilizer. Unfortunately, the harvest that season was quite poor, and only 10 of the 46 farmers sampled for SAFI got more than a 4 kilogram difference between the two plots. We compared next years' adoption among those of those farmers sampled for SAFI and those who were not. A first observation is that the following year's adoption is higher among those who were sampled for SAFI than among the other pilot farmers (44% on average in the second year). Next, the 10 SAFI farmers do adopt fertilizer more the second time, but there is evidence of substitution: the difference in adoption between SAFI and non SAFI farmers in this group is only 10% (which is not significant, due to the very small sample size).

After Pilot IV, we asked each farmer to sell us *all* of the maize from each of his 2 plots,[3] so each farmer had a fair amount of money on hand (an average of 206 Ksh per farmer, which is enough to buy approximately 7 kilograms of fertilizer).[4] We then offered the SAFI program to a random subsample of all farmers, and asked them to decide right away. They were allowed to buy any quantity of fertilizer they wanted, at market price. They were allowed to sell additional maize to purchase additional fertilizer, but in practice most of the farmers who took up the scheme purchased less than the full amount. 24 out of the 29 farmers sampled for SAFI accepted the scheme, purchasing some time large quantities of fertilizer.

There were several relevant differences between SAFI II and SAFI IV: the farmers had tried on fertilizer before; they knew us better; they were not given any time to procrastinate since they had to accept the offer on the day it was made; and finally, they had sold maize, so were given a large quantity of maize. The following programs were designed to understand which features affected the most the propensity to accept the scheme.

To keep the level of trust and the familiarity with fertilizer constant, SAFI IVb, SAFI, and SAFI VI were all realized with farmers that had participated in the pilot experiments.

- Committing now or later: SAFI V.

After pilot V, a group of farmers were offered the SAFI program. In this case, we had only purchased a very small quantity of fertilizer from each farmer. We randomly selected farmer for three versions of the SAFI program. In the first version, we offered them the program on the day of the last visit to them (the profit intervention). In the second version, we offered the program and said that we would come back in a few days to collect the money. In the last version, we offered the program but said that we would only come back at harvest time to collect the money and deliver fertilizer. This version

[3] We needed to buy this maize for our profit calculations.
[4] The average price used for maize bought that season was 18.75 Ksh.

does not offer any commitment to the farmer, but offer him all the other services that may be confounding the effect of the program in other cases: the fertilizer is available in small quantity, it is delivered at home for free. Finally, the farmer probably think that ICS are endorsing the use of fertilizer (after all, the field officer just finished conducting a field trial on this farmer's farm), and may want to humor the field officer and buy some fertilizer in order to maintain a good relationship with the NGO. The results are striking: in all three version, about 50% of the farmers expressed interest in purchasing fertilizer (or a commitment to purchase fertilizer). In the first version, since the purchase had to be made on that day, all the farmers who had expressed interest in the scheme actually purchased fertilizer. In the second version, only 5 out of the 16 farmers who had been offered the scheme actually had the money they had planned to have a few days later, when the field officer came back to collect it (8 had expressed some interest). In the last version, none of the 8 farmers who had expressed interest purchased fertilizer at top-dressing time. This last result suggests that none of the reasons other than commitment why the farmers may have taken up the scheme probably explain it. The contrast between the second and the first result suggest that any extra cash available at any point disappears extremely rapidly. This strongly suggests that farmers behave like hyperbolic discounters, and that the commitment device help them to overcome this problem.

We offered the SAFI program again in the following year to a subset of the farmers who had been offered SAFI 4. They still had the option of selling us maize to buy fertilizer. However, since they were not compelled to sell maize for some other reason, they were left the option of taking a few days to collect the money. The take up of SAFI 4 exhibits the same pattern as the take up for SAFI 2: Most (80%) of the farmers initially expressed interest, but after a few days, only 30% eventually purchased for fertilizer. This is still substantially higher than the fraction of farmers who are using fertilizer in the control group, which suggest that, even if all the farmers who were going to use fertilizer anyway purchased fertilizer from us, the program increased the fraction of people who are using fertilizer.

- Cash or maize

A difference between SAFI II, SAFI III, SAFI IVb and SAFI V on the one hand, and SAFI IV on the other hand, is that in the SAFI IV case, a reasonably large sum of money was given to the farmer in any case. Except for SAFI III which was particular since it was offered only to 10 people with excellent results, the take up of the scheme is lower in all of these versions (including the versions with the highest level of commitment in SAFI V). The initial level of interest in the scheme is also higher in most instances. This could be due to the fact that the farmers are particularly unwilling to carry large amount of cash. This would be consistent with the observations that very few farmers sell any maize. It would also be consistent with hyperbolic discounting, arising either from the individual or from the family: introducing a small cost of transforming the maize into cash may be enough to discourage impulse purchases from individuals. To test this hypothesis, we tried out both programs in SAFI VI. In the first group, we asked the farmers to sell us some maize for the purpose of the pilot experiment, and offered the scheme to a subset of these farmers. In the second group, we did not ask the farmers to sell us any maize, but offered them the option to sell it if they wanted to purchase a fertilizer voucher with it. They also had the option to use cash otherwise available to them. The results are exactly in line with the hypothesis that holding cash makes farmers much more willing to accept the scheme: 71% of those from whom we had purchased fertilizer accepted the scheme. 50% of those from who we had not purchased the fertilizer accepted the scheme. While the samples are too small to statistically distinguish these two numbers, they do suggest that maize may be in part a commitment device, and that farmers are more willing to hold onto it than onto cash.

3. Conclusions: Experiments in Progress and future plans

[LINKS BETWEEN LOW SAVINGS AND LOW ADOPTION IN THE ENVIRONMENT WITH EPIDEMIOLOGICAL MODEL OF LEARNING: LOW SAVINGS MAKES IT MORE LIKELY THAT FARMERS WILL ABANDON AND HIGH ABANDON MAKES IT LESS LIKELY FARMERS TALK TO EACH OTHERS]

In addition from collecting more data about adoption, as well as setting up long term pilot programs on a few farms in order to assess the long term effect of fertilizer on the soil fertility, as well as the risk associated with the use of fertilizer, our current work seeks to implement learning and savings programs on a larger scale, as well as trying to test more refined hypothesis on both subjects.

For learning, we have set up demonstration plots in schools, and distributed starter kits to parents in these schools. The results on the pilot farmers suggest that a combination of starter kits and demonstration plots, if farmers do attend the key periods may be as effective as the pilot farms in conveying knowledge about fertilizer. Another question of interest is how much weight people put on their prior, their own returns and the returns of others when forming their posterior about fertilizer returns and when deciding whether or not to use fertilizer. We have extensive data on priors, both for treatment and for comparison farmers. A first pass will be to use the cross sectional variation on returns, and to exploit the data on prior and posteriors, which we have not yet done. A second approach would be to use different quantity of fertilizer per hole with different farmers, to obtain different returns and assess the impact of the rates of returns. This experiment would also test "maize illusion", since lower returns are obtained both with the smallest quantity of fertilizer per hole and the highest quantity of fertilizer per hole, but the yield is largest with the highest quantity per hole.

On the savings issue, there are several questions that interest us, and we set up (or are in the planning stage for) several interventions to try to shed light on these issues.

1) SAFI as a development program

SAFI was more effective when people had had prior contact with the NGO field officer, and had tried fertilizer in the demonstration plot in their own farms. Individual level demonstration plots are not practical as development program, however, since they involve several visits to an individual farm. Starter kits program are much less onerous,

and provide the farmers with both a first contact with an NGO and a first hand experience with fertilizer. We will therefore try to combine the SAFI program with a large scale version of the demonstration schools and starter kits program.

2) Are families or individuals hyperbolic discounters ?

An extended family whose members have the right to make a claim on the income at random times will behave, in reduced form, like an individual who is a hyperbolic discounter: To protect one's income against future claims, individuals will eat it before having the opportunity to invest. Can we distinguish between this hypothesis and the hypothesis that these are the individuals who compose these families who are hyperbolic discounters? To shed light on this issue, we will buy the maize of a randomly selected group of farmers, and we will administer an expenditure survey to these farmers (and a group of comparison farmers) in the following two weeks. In this way, we should be able to "trace" what has happened to the cash we gave to these farmers: Was it used for school fees for relative or neighbors, or for consumption for the individual? This experiment can also be used to test on a large sample the idea that farmers are more likely to choose SAFI if they have cash on hand than if they have maize, even if they are provided a way to freely transform cash into maize: will farmers be more likely to take up the SAFI scheme after they were given cash then if they have to decide themselves whether or not to sell the maize to take up the scheme?

3) Are farmers naïve or rational hyperbolic discounters?

To answer this question, once we set up a large scale version of the SAFI program, we will form three distinct groups: One group is offered the SAFI program, with an obligation to commit on the day of the visit. One group is offered the SAFI program and can CHOOSE whether or not they want to commit on that day, or pay for it later. One group is offered the same choice, but is reminded that many people find it hard to honor these types of commitment. If people are sophisticated hyperbolic discounters, they should choose to commit now, rather than later.

The results from these experiments, many of which will be available by the time of the conference, should complement and shed light on the results we have already obtained. Together, they will provide a rich set of facts and data, which will allow us to present a new test of behavioral hypothesis with field experiments conducted in a real-world developing country setting. These results may provide a rationale for marketing boards, which subsidize inputs, and for the decision of sugar producing companies to subsidize fertilizer for sugar cane growers.

References

Conley, Timothy and Christopher Udry (2000) "Learning About a New Technology: Pineapple in Ghana," Yale Economic Growth Center Discussion Paper: 817.

Foster, Andrew D. and Mark R. Rosenzweig (1995) "Learning by Doing and Learning from Others: Human Capital and Technical Change in Agriculture," Journal of Political Economy, Vol. 103 (6), pp. 1176-1209.

Munshi, Kaivan (1998) "Social Learning in a Heterogeneous Population: Technology Diffusion in the Indian Green Revolution," forthcoming in *Journal of Development Economics*.