Nudging Farmers to Use Fertilizer:

Theory and Experimental Evidence from Kenya

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While many developing-country policymakers see heavy fertilizer subsidies as critical to raising agricultural productivity, most economists see them as distortionary, regressive, environmentally unsound, and argue that they result in politicized, inefficient distribution of fertilizer supply. We model farmers as facing small fixed costs of purchasing fertilizer, and assume some are stochastically present-biased and not fully sophisticated about this bias. Even when relatively patient, such farmers may procrastinate, postponing fertilizer purchases until later periods, when they may be too impatient to purchase fertilizer. Consistent with the model, many farmers in Western Kenya fail to take advantage of apparently profitable fertilizer investments, but they do invest in response to small, time-limited discounts on the cost of acquiring fertilizer (free delivery) just after harvest. Later discounts have a smaller impact, and when given a choice of price schedules, many farmers choose schedules that induce advance purchase. Calibration suggests such small, time-limited discounts yield higher welfare than either laissez faire or heavy subsidies by helping present-biased farmers commit to fertilizer use without inducing those with standard preferences to substantially overuse fertilizer.

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"The rest of the world is fed because of the use of good seed and inorganic fertilizer, full stop. This technology has not been used in most of Africa. The only way you can help farmers get access to it is give it away free or subsidize it heavily."
Stephen Carr, former World Bank specialist on Sub-Saharan African agriculture, quoted in Dugger, 2007.

Many agricultural experts see the use of modern inputs, in particular fertilizer, as the key to agricultural productivity. Pointing to the strong relationship between fertilizer use and yields in test plots, they argue that fertilizer generates high returns and that dramatic growth in agricultural yields in Asia and the stagnation of yields in Africa can largely be explained by increased fertilizer use in Asia and continued low use in Africa (Morris, Kelly, Kopicki, and Byerlee, 2007). Based on this logic, Ellis (1992) and Sachs (2004) argue for fertilizer subsidies. Many governments have heavily subsidized fertilizer. In India, for example, fertilizer subsidies amounted to 0.75 percent of GDP in 1999–2000 (Gulati and Narayanan, 2003). In Zambia, fertilizer subsidies consume almost 2 percent of the government's budget (World Development Report, 2008).

In contrast, the Chicago tradition associated with Schultz (1964) starts with the presumption that farmers are rational profit maximizers, so subsidies will distort fertilizer use away from optimal levels. Others have argued that fertilizer subsidies create large costs beyond these Harberger triangles. They are typically regressive as wealthier farmers and those with more land often benefit most from subsidies (Donovan, 2004), and loans for fertilizer often go to the politically connected and have low repayment rates. Moreover, while moderate fertilizer use is environmentally appropriate, overuse of fertilizer induced by subsidies can cause environmental damage (World Bank, 2007). Furthermore, fertilizer subsidies may lead to government involvement in fertilizer distribution, politicization, and very costly failures to supply the right kind of fertilizer at the right time.

Partly due to the dominance of the anti-subsidy view among economists and international financial institutions, fertilizer subsidies have been rolled back in recent decades. Recently, however, they have seen a resurgence. For example, after Malawi's removal of fertilizer subsidies was followed by a famine, the country reinstated a two-thirds subsidy on fertilizer. This was followed by an agricultural boom which many, including Jeffrey Sachs, attribute to the restoration of the fertilizer subsidies (Dugger, 2007).

A key assumption in the Chicago tradition case against fertilizer subsidies is that farmers would use the privately optimal quantity of fertilizer without subsidies. To reconcile low fertilizer use with the large increases in yield from fertilizer use found in agricultural research stations, economists often note that conditions on these stations differ from those on real-world farms, and returns may be much lower in real conditions, where farmers cannot use other inputs optimally. There is evidence that fertilizer is complementary with improved seed, irrigation, greater attention to weeding, and other changes in agricultural practice that farmers may have difficulty in implementing. However, in previous work we implemented a series of trials with farmers on their own farms in a region of Western Kenya where fertilizer use is low. Those trials showed that when fertilizer is used in limited quantities, it generates returns of 36 percent over a season on average, which translates to 70 percent on an annualized basis (Duflo, Kremer, and Robinson, 2008), even without other changes in agricultural practices. Low investment rates in the face of such high returns are particularly puzzling since fertilizer is well-known and long-used in the area. Moreover, since fertilizer is divisible, standard theory would not predict credit constraints would lead to low investment traps in this context.[1] There could of course be fixed costs in buying or learning to use fertilizer (for example, making a trip to the store). Indeed, small fixed costs of this type will play an important role in our model. However, such costs would have to be implausibly large to justify the lack of fertilizer investment in the standard model.[2]

In this paper we argue that just as behavioral biases limit investment in attractive financial investments in pension plans by workers in the United States (e.g., Choi, Laibson and Madrian, 2008), they may limit profitable investments in fertilizer by farmers in developing countries. We set out a simple model of biases in farmer decision-making inspired by models of procrastination from the psychology and economics literature (see O'Donoghue and Rabin, 1999). In the model some farmers are (stochastically) present-biased and at least partially naïve, systematically underestimating the odds that they will be impatient in the future, at least in the case when they are patient today. Going to the store, buying fertilizer, and perhaps deciding what type of fertilizer to use and how much to buy, involves a utility

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[1] As discussed below, profits are concave rather than convex in fertilizer use per unit of land area. Moreover, since farmers always have the option of applying fertilizer intensely on some land while leaving other pieces of land unfertilized, returns must be non-increasing.

[2] For instance, consider a farmer with an hourly wage of $0.13 over for whom round trip travel to town to buy fertilizer takes one hour and who can only initially afford $1 worth of fertilizer. Since half a teaspoon of top

cost. Even if this cost is small, so long as farmers discount future utility, even farmers who plan to use fertilizer will choose to defer incurring the cost until the last moment possible, if they expect to still be willing to purchase the fertilizer later. However, farmers who end up being impatient in the last period in which buying is possible will then fail to invest in fertilizer altogether.

Under the model, heavy subsidies could induce fertilizer use by stochastically hyperbolic farmers, but they also could lead to overuse by farmers without time consistency problems. The model implies that if offered just after harvest (when farmers have money) small, time-limited discounts on fertilizer could induce sizeable changes in fertilizer use. In particular, early discounts of the same order of magnitude as the psychic costs associated with fertilizer purchase can induce the same increase in fertilizer use as much larger discounts of the order of magnitude of the out-of-pocket costs of fertilizer later in the season. Moreover, *ex ante* (before the harvest) some farmers would choose to be eligible for the discount early on, so as to have an option to commit to fertilizer use.

In collaboration with International Child Support (Kenya) a non-government organization (NGO), we designed and tested a program based on these predictions. Using a randomized design, we compared the program to alternative interventions, such as standard fertilizer subsidies or reminders to use fertilizer. The results are consistent with the model. Specifically, offering free delivery to farmers early in the season increases fertilizer use by 46 to 60 percent. This effect is greater than that of offering free delivery, even with a 50 percent subsidy on fertilizer, later in the season.

Following an approach similar to O'Donoghue and Rabin (2006), we use the model to analyze the impact of different policies depending on the distribution of patient, impatient, and stochastically present-biased farmers. Calibrations based on our empirical results suggest that 71 percent of farmers are stochastically present-biased, 16 percent are always patient, and 13 percent are always impatient. This yields a prediction that roughly 55 percent of farmers should never use fertilizer in the three seasons we follow them. Empirically, 52 percent of comparison farmers do not use fertilizer in any of the three seasons for which we have data. The calibrated model matches other moments in the data, in particular the proportion of farmers who take up fertilizer when given the choice of which date they would like to be offered free fertilizer delivery.

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dressing fertilizer yields returns of 36 percent over a season, netting out the lost wages would leave the farmer with a 23 percent rate of return over a few months.

The calibration suggests that a "paternalistic libertarian" (Thaler and Sunstein, 2008) approach of small, time-limited discounts could yield higher welfare than either laissez faire policies or heavy subsidies, by helping stochastically hyperbolic farmers commit themselves to invest in fertilizer while avoiding large distortions in fertilizer use among time-consistent farmers, and the fiscal costs of heavy subsidies.

The rest of the paper is structured as follows: Section 2 presents background information on agriculture and fertilizer in Western Kenya. Section 3 presents the model and derives testable predictions. Sections 4 lays out the program used to test the model; Section 5 reports results, and Section 6 calibrates the model and then uses the calibrated model to compare welfare under laissez faire, heavy subsidies, and small time-limited subsidies. Section 7 examines alternative hypotheses, and Section 8 concludes with a discussion of the potential for realistically scaling up small, time-limited subsidies in a way that would not involve excessive administrative costs.

2. Background on Fertilizer use in Western Kenya

Our study area is a relatively poor, low-soil fertility area in Western Kenya where most farmers grow maize, the staple food, predominantly for subsistence. Most farmers buy and sell maize on the market, and store it at home. There are two agricultural seasons each year, the "long rains" from March/April to July/August, and the less productive "short rains" from July/August until December/January.

Based on evidence from experimental model farms (see Kenyan Agricultural Research Institute, 1994), the Kenyan Ministry of Agriculture recommends that farmers use hybrid seeds, Di-Ammonium Phosphate (DAP) fertilizer at planting, and Calcium Ammonium Nitrate (CAN) fertilizer at top dressing (when the maize plant is knee-high, approximately one to two months after planting). Fertilizer is available in small quantities at market centers (and occasionally in local shops outside of market centers). Our rough estimate is that the typical farmer would need to walk for roughly 30 minutes to reach the nearest market center. Although there is a market for reselling fertilizer, it is not very liquid and resale involves substantial transaction costs.[3]

Experiments on actual farmer plots suggest low, even negative returns to the combination of hybrid seeds and fertilizer at planting and top dressing, (Duflo, Kremer, and

[3] Discussions with people familiar with the area suggest reselling fertilizer typically involves a discount of approximately 20 percent of the cost of fertilizer in addition to the search costs of finding a buyer.

Robinson, 2008), although it is plausible that returns might be higher if farmers changed other farming practices. Similarly, the use of a full teaspoon of fertilizer per plant as top dressing is not profitable, because farmers realize large losses when rains fail or are delayed and seeds do not germinate. However, a more conservative strategy of using only one half teaspoon of fertilizer per plant as top dressing, after it is clear that seeds have germinated, yields a high return and eliminates much of the downside risk. The average farmer in our sample plants just under one acre of maize. Using one half teaspoon of fertilizer per plant increases the yield by about $54 per acre and costs $40 per acre, a 36 percent return over the several months between the application of fertilizer and harvest (70 percent on an annualized basis) on real-world farms even in the absence of other complementary changes in farmer behavior. The incremental yield associated with the second half teaspoon of fertilizer is valued at approximately $18 per acre, corresponding to a negative return of around -55 percent at full price, but a 30 percent return under a two-thirds subsidy, very close to the return to the first half teaspoon at full price.

However, despite these large potential returns to applying limited quantities of fertilizer as top dressing, only 40 percent of farmers in our sample report ever having used fertilizer and only 29 percent report using it in at least one of the two growing seasons before the program.[4] When asked why they do not use fertilizer, farmers rarely say fertilizer is unprofitable, unsuitable for their soil, or too risky: instead, they overwhelmingly reply that they want to use fertilizer but do not have the money to purchase it. Of farmers interviewed before the small-scale agricultural trials we conducted, only 9 percent said that fertilizer was unprofitable while 79 percent reported not having enough money. At first this seems difficult to take at face value: fertilizer can be bought in small quantities (as small as one kilogram) and with annualized returns of 70 percent, purchasing a small amount and investing the proceeds would eventually yield sufficient money to generate sufficient funds to fertilize an entire plot. Even poor farmers could presumably reallocate some of the proceeds of their harvest from consumption to fertilizer investment per acre.

One way to reconcile farmers' claims that they do not have money to buy fertilizer with the fact that even poor farmers have resources available at the time of harvest is that farmers may initially intend to save in order to purchase fertilizer later but then fail to follow through on those plans. In fact, 97.7 percent of farmers who participated in the demonstration plot

[4] These figures differ slightly from those in Duflo, Kremer, and Robinson (2008) because the sample of farmers differs.

program reported that they planned to use fertilizer in the following season. However, only 36.8 percent of them actually followed through on their plans and used fertilizer in the season in which they said they would. Thus, it appears that even those who are initially planning to use fertilizer often have no money to invest in fertilizer at the time it needs to be applied, for planting or top dressing, several months later.

3. Model

Below we propose a model of procrastination similar to those advanced to explain the failure of many workers in developed countries to take advantage of profitable financial investments (O'Donoghue and Rabin, 1999) and derive testable predictions. In the model, some farmers are present-biased, with a rate of time preference that is realized stochastically each period. When they are very present-biased, farmers consume all they have. When they are moderately present-biased, farmers make plans to use fertilizer. But early in the season, patient farmers overestimate the probability that they will be patient again, and thus they postpone the purchase of fertilizer until later, and save in cash instead. Later, if they turn out to be impatient, they consume all of their savings instead of investing in fertilizer, resulting in a lower usage of fertilizer than the farmer in the early period would have wanted.

3.1 Assumptions

Preferences and Beliefs

Suppose that some fraction of farmers γ, are *patient*. They are time consistent and exponentially discount the future at rate β_H.

A proportion ϕ is *(stochastically) present-biased*, and systematically understate the extent of this present bias. In particular suppose that in period k, these farmers discount every future period at a stochastic rate β_k (for simplicity we assume that there is no discounting between future periods). In each period k, with some probability p, the farmer is fairly patient ($\beta_k = \beta_H$), and with probability $(1-p)$, the farmer is quite impatient ($\beta_k = \beta_L$). Furthermore, while farmers do recognize that there is a chance that they will be impatient in the future, they overestimate the probability that they will be patient. Specifically, the probability that a patient farmer believes that she will still be patient in the future is $\tilde{p} > p$.

There are several ways to interpret this stochastic rate of discount. One interpretation is that farmers are literally partially naïve about their hyperbolic discounting, as in the original

O'Donoghue and Rabin (1999) framework. An alternative interpretation, along the lines of Banerjee and Mullainathan (2008a), is that a consumption opportunity occasionally arises (e.g., a party) that is tempting to the farmer in that period, but which is not valued by the farmer in other periods.

A final proportion ψ are *always impatient* so that $\beta_k = \beta_L$ in all periods. All farmers are one of these three types so $\gamma + \phi + \psi = 1$.

Finally, for simplicity, we assume per-period utility in any period is simply consumption in that period, less a small utility cost associated with shopping for fertilizer and the time cost associated with deciding what quantity of fertilizer to buy, which will be described below.

Timing and Production

There are four periods. *Period 0* is immediately prior to the harvest. The farmer does not plan to save, consume or purchase fertilizer in this period, but we will later consider a situation in which the farmer can pre-commit to different patterns of fertilizer pricing in this period. We will initially abstract from *period 0* but later allow the farmer to make a choice of a price schedule for fertilizer in *period 0*.

In *period 1*, the farmer harvests maize, receives income $x > 2$, and can allocate income between consumption, purchase of fertilizer for the next season, and a short-run investment that yields liquid returns by the time fertilizer needs to be applied. Some farmers, such as those who have shops where they can use more working capital, will have high return investments that yield liquid returns over a short period, whereas others will have lower return investment opportunities. We therefore assume the net return *R* is high ($\overline{R}$) for a proportion λ of farmers, and low ($\underline{R} > 0$) for the rest. Farmers know their rate of return with certainty.

Farmers can choose to use zero, one or two units of fertilizer. We assume discreteness of fertilizer investment to keep the analysis tractable and to parallel our previous empirical work, which examined the returns to zero, half or one teaspoon of fertilizer per plant. However, the discreteness does not drive our results.

Let p_{f1} denote the price of fertilizer in period 1. Purchasing any fertilizer also entails a small utility cost f (encompassing the time cost of going to the shop to buy the fertilizer, as well as deciding what type to use and how much to buy). This cost is independent of the amount of fertilizer purchased. Note that while fertilizer is a divisible technology, the assumption that there is some fixed cost of shopping for fertilizer is consistent with our finding that few farmers use very small amounts of fertilizer—they tend to either use no fertilizer or fertilize a significant fraction of their crop.[5]

At the beginning of *period 2*, which can be thought of as the time of planting for the next season, those who have invested in period 1 receive $1 + R$ for each unit invested. Farmers receive no additional income during this period: farmers can only consume by using their savings and, if they have sufficient wealth, purchase either one or two units of fertilizer at price p_{f2} per unit incurring *cost f* if they do so. Borrowing is not possible.

The cost of producing fertilizer is assumed to be one, so that under competition and laissez-faire, $p_{f1} = p_{f2} = 1$. We will also consider the impact of heavy government subsidies of the type adopted by Malawi, under which $p_{f1} = p_{f2} = \frac{1}{3}$, as well as a small, time-limited subsidy in which $p_{f1} < 1$ and $p_{f2} = 1$.

In *period 3*, farmers receive income $Y(z)$, where *z* is the amount of fertilizer used. Define the incremental yield to fertilizer as $y(1) = Y(1) - Y(0)$ and $y(2) = Y(2) - Y(1)$.

We assume that the cost of reselling fertilizer is sufficiently large to discourage even impatient farmers from doing so. Maize, on the other hand is completely liquid and can be converted to cash at any time. Empirically, maize is much more liquid than fertilizer and can be easily traded at local markets.

Assumptions on Parameters

We assume:

$$\beta_H y(1) > 1 + f \tag{1}$$

$$\frac{1}{1+\overline{R}} + \beta_L f > \beta_L y(1) > \frac{1}{3} + f \tag{2}$$

$$\frac{1}{3\beta_H} < y(2) < 1 \tag{3}$$

$$\frac{1}{3\beta_L(1+\overline{R})} > y(2) \tag{4}$$

The first condition ensures that a patient farmer prefers using one unit of fertilizer to zero units of fertilizer, even if it has to be purchased right away. The second implies that an impatient farmer will prefer to consume now rather than to save in order to invest in fertilizer if the price is not heavily subsidized, even if it is possible to delay the decision and shopping

[5] For instance, among farmers who were not offered free delivery or subsidized fertilizer, between 20 percent and 30 percent use top dressing fertilizer in a given season, but over 75 percent of those who do use fertilizer use it on their entire plot.

costs of purchasing fertilizer to a future period, and even if the rate of return to the period 1 investment is high. The second condition also ensures that impatient farmers will buy fertilizer if it is heavily subsidized at two-thirds the cost of fertilizer, whatever the return to their period 1 investment opportunity. The third condition implies that the second unit of fertilizer is not profitable at the full market price (and that therefore no farmers will want to use more than one unit at full price), and also implies that patient farmers will prefer to use two units at a heavy subsidy of two-thirds of the cost of fertilizer (note that the third condition does not include the shopping cost f because the cost is incurred if the farmer uses any fertilizer and does not depend on the quantity used). The fourth condition implies that impatient farmers will not use a second unit of fertilizer even with a heavy subsidy of two-thirds the cost of fertilizer.

These conditions match our empirical evidence on the rates of return to fertilizer (Duflo, et al., 2008) since we find that the return to the first unit of fertilizer is high, and that the incremental return to the second unit is negative at market prices. The assumptions are also consistent with evidence that the incremental return to the second unit at a two-thirds subsidy is similar to the return to the first unit at market prices, which suggests that patient farmers (who use fertilizer without a subsidy) would be likely to use two units at subsidized prices.

Finally, for completeness, we assume that $\beta_H(1+\overline{R})>1$, $\beta_L(1+\overline{R})<1$, $\beta_H(1+\underline{R})>1$, which implies that patient period 1 farmers with high returns always make the period 1 investment while impatient farmers never do.

In subsections 3.2, 3.3, and 3.4 we consider farmer behavior under laissez-faire, in which $p_{f1}=p_{f2}=1$; traditional heavy subsidies of the type adopted in Malawi in which $p_{f1}=p_{f2}=\frac{1}{3}$; and c) time-limited discounts under which $p_{f1}<1$ and $p_{f2}=1$.

3.2 Farmer Behavior Under Laissez-faire ($p_{f1}=p_{f2}=1$)

Under laissez-faire, by assumption (1), the proportion γ of farmers who are always patient in every period will always use one unit of fertilizer. All will save at rate *R* in period 1 and buy fertilizer in period 2. By assumption (2), the proportion ψ of farmers who are always impatient will never use fertilizer. By our other assumptions, they will not avail themselves of the investment opportunity, whatever the return.

Now consider the problem of a stochastically present-biased farmer deciding whether (and when) to buy fertilizer. To solve the model, we work backwards, beginning with the problem of a farmer in period 2, who must choose between consuming one unit, or investing it in fertilizer. Assumption (1) implies that a farmer who has sufficient wealth and is patient in period 2 will use fertilizer. Assumption (2) implies that a farmer who is impatient in period 2 will not use fertilizer.

Now consider the problem of a farmer in period 1. First, observe that a farmer who is impatient in period 1 will consume x, and will not save: seen from period 1, the gain from investing in one unit of fertilizer is at best $\beta_L y(1) - \beta_L f$ (if the farmer ends up being patient and buys fertilizer), which, by assumption (2), is smaller than $\frac{1}{1+\overline{R}}$ (the loss in consumption in period 1 from saving to purchase fertilizer in period 2, for a farmer with a high return saving opportunity). This farmer will also not save since we assume that $\beta_L(1+\overline{R}) < 1$.

Now consider a farmer who is patient in period 1. Investing in fertilizer today dominates consuming everything today: the farmer's utility if she purchases one unit of fertilizer and consumes the rest is $x - 1 - f + \beta_H y(1)$, while her utility is x if she consumes everything today. By assumption (1), utility from buying fertilizer is higher than not buying.

Now, in period 1, should a patient farmer buy the fertilizer right away, or plan to wait to do it in period 2? If a farmer who is patient today has a sufficiently high subjective probability of being patient again (and therefore a high probability of buying fertilizer in period 2), then it is best to wait, and thus realize the return on the period 1 investment and postpone paying the utility cost of buying fertilizer until period 2. To see that postponing may be optimal, note that if the farmer waits, ends up being patient in period 2, and thus purchases fertilizer (which she believes will happen with probability $\tilde{p}$), her utility is

$$x - \frac{1}{1+R} + \beta_H(y(1) - f) \tag{5}$$

If she ends up being impatient (which she believes will happen with probability $1 - \tilde{p}$, her utility is $x - 1 + \beta_H$.

Thus, waiting is optimal if:

$$x - \frac{1}{R+1} + \tilde{p}\beta_H(y(1) - f) + (1-\tilde{p})\beta_H > x - 1 - f + \beta_H y(1) \tag{6}$$

Rearranging, we find that the farmer will wait if:

$$f(1 - \tilde{p}\beta_H) + \frac{R}{1+R} > \beta_H(y(1) - 1)(1 - \tilde{p}) \tag{7}$$

When $\tilde{p} = 0$, the right hand side is equal to $\beta_H(y(1) - 1)$. If we assume that the utility cost of using fertilizer is small enough that $\beta_H(y(1) - 1)$ is larger than $f + \frac{R}{1+R}$, then the right hand side of the inequality is larger than the left hand side. Both sides of the inequality decline with $\tilde{p}$, but the right hand side is steeper. For $\tilde{p} = 1$, the left hand side is larger than the right hand side (which is equal to zero). Thus, for each *R*, there is a $\tilde{p}^*(R)$ in the interval (0,1) such that for every $\tilde{p} > \tilde{p}^*(R)$, a farmer who is intending to use fertilizer later prefers to invest in the first period investment opportunity, and plans to buy fertilizer in period 2. It is easy to see that $\tilde{p}^*(R)$ is decreasing with *R*: the higher the return to the period 1 investment, the more valuable it is for the farmer to wait.

For the remainder of the model, we assume that $\tilde{p} > \tilde{p}^*(R)$. Note that since impatient period 1 farmers will not save in any case, it is not necessary that they believe they will be more patient in the future than they are in the present for this procrastination problem to arise. Instead, it is only necessary that patient farmers overestimate the probability that they will continue to be patient in the future. This tendency to believe that future tastes will more closely resemble current tastes than they actually will, termed "projection bias," has found considerable empirical support (Loewenstein, O'Donoghue, and Rabin, 2003).

3.3 Farmer Behavior Under Malawian-Style Heavy Subsidies ($p_{f1} = p_{f2} = \frac{1}{3}$)

One potential way to address underinvestment in fertilizer would be through heavy, Malawian-style subsidies. Under heavy subsidies, by assumption (3), farmers who are always patient will buy two units of fertilizer, and by assumption (2), farmers who are always impatient will buy one unit.

To solve for the behavior of the stochastically impatient farmers in this case, we again work backwards from period 2. Assumption (2) implies that even farmers who are impatient in period 2 will use one unit of fertilizer if $p_{f2} = \frac{1}{3}$, while assumption (4) implies that impatient farmers will not want to use two units of fertilizer. A farmer who is impatient in period 2 will thus purchase exactly one unit if he has the wealth do to it and has not already purchased it earlier.

Now consider the case of a stochastically hyperbolic farmer deciding whether to purchase fertilizer in period 1. First consider a farmer who is patient in period 1. Assumption (3) implies that a patient farmer wants to either purchase two units, or save enough to buy two units. Recall that it is efficient for farmers to purchase all of their fertilizer in a single period since by doing so they only need to pay the shopping cost of fertilizer once.

If a farmer buys two units of fertilizer immediately, her utility is:

$$x - \frac{2}{3} - f + \beta_H(y(2) + y(1)) \tag{8}$$

If the farmer instead plans to use fertilizer and saves at return *R* for future fertilizer use, she will purchase two units of fertilizer if she is patient in period 2. If, however, she is impatient in period 2 she will purchase only 1 unit. Thus, her expected utility from waiting is:

$$x - \frac{2}{3(1+R)} + \beta_H[y(1) - f + \tilde{p}y(2) + (1-\tilde{p})\frac{1}{3}] \tag{9}$$

Thus, she will prefer to save and plan to buy fertilizer later if:

$$\frac{2R}{3(1+R)} + f(1-\beta_H) > \beta_H(y(2) - \frac{1}{3})(1-\tilde{p}) \tag{10}$$

By reasoning similar to the case without a subsidy, there is a threshold $\tilde{p}^{**}(R)$ such that if $\tilde{p} > \tilde{p}^{**}(R)$, farmers who are patient in period 1 will wait until period 2 to purchase (it is also easy to see that the threshold decreases with *R*, so those with higher returns to investment in period 1 will be more likely to defer purchases). Depending on parameter values, $\tilde{p}^{**}(R)$ could be smaller or larger than $\tilde{p}^{*}(R)$. However, if the incremental return of the second unit of fertilizer at the subsidized price is greater or equal to the incremental return on the first unit of fertilizer at an unsubsidized price (i.e., $3y(2) \geq y(1)$), then $\tilde{p}^{**}(R)$ is larger than $\tilde{p}^{*}(R)$. Below we assume that $\tilde{p}$ is above both thresholds. Note that this is the best case scenario for heavy subsidy; if $\tilde{p}$ was lower than $\tilde{p}^{**}(R)$, the stochastically impatient farmers who are patient in period 1 would all buy two units in period 1, and thus would all end up overusing fertilizer.

Now, consider a stochastically patient farmer who happens to be impatient in period 1. Given our assumptions, she wants to use one and only one unit of fertilizer at the heavily subsidized price. If she saves, she will thus save enough to purchase one unit, and she will always follow through on this plan. Therefore, there is no time inconsistency issue for her, and she will postpone buying fertilizer until period 2, and will buy exactly one unit.

Overall, a heavy subsidy will induce 100 percent fertilizer usage, but will cause the always-patient farmers and the stochastically impatient farmers who happen to be patient in both periods to overuse fertilizer.

3.4 Impact of Time-Limited Discount ($p_{f1} < 1$ and $p_{f2} = 1$)

Consider the impact of a small discount on fertilizer, valid in period 1 only (which corresponds to the case in which $p_{f1} < 1$ and $p_{f2} = 1$). Consider a discount that is not large enough to make purchasing two units of fertilizer profitable, even for a patient farmer (we will see that this is a reasonable assumption since the necessary discount will be small).

To make a patient period 1 farmer prefer purchasing fertilizer in period 1 to waiting to purchase fertilizer in period 2, the period 1 price needs to be such that:

$$x - \frac{1}{1+R} + \tilde{p}(y(1) - f) + (1-\tilde{p})\beta_H < x - p_{f1} - f + \beta_H y(1) \tag{11}$$

If we define $p^*_{f1}(R)$ as the price that just satisfies this condition for a farmer with return to investment *R*, then $p^*_{f1}(R)$ is given by:

$$p^*_{f1}(R) = f(\tilde{p}\beta_H - 1) + \beta_H(1-\tilde{p})(y(1) - 1) + \frac{1}{1+R}. \tag{12}$$

Note that when $\tilde{p}$ is close to 1, the price $p^*_{f1}(R)$ differs from 1 by a term proportional to the utility cost *f*, plus the foregone return to investment ($\frac{R}{1+R}$). The intuition is that the only additional costs that a farmer who is patient in period 1 has to immediately bear when choosing between investing one unit in the period 1 investment and buying one unit of fertilizer are the utility cost of purchasing the fertilizer, and the foregone investment opportunity. Thus, the farmer just needs to be compensated for incurring the decision and shopping cost f up front, rather than later, as well as for the foregone returns to the period 1 investment. If the returns to the period 1 investment are low, even a small discount, or a reduction in the utility cost (such as free delivery in period 1) may then be sufficient to induce the farmer to switch to buying fertilizer in period 1, instead of relying on her period 2 self to purchase fertilizer.

It is useful to compare the impact of a subsidy in period 1 to an unanticipated subsidy in period 2. An unanticipated period 2 subsidy will not affect the period 1 decision. An impatient period 2 farmer with sufficient wealth will decide to use fertilizer if $f - p_{f2} < \beta_L y(1)$. We denote the p_{f2}, which just satisfies this inequality as p^*_{f2}. In order to induce fertilizer purchase, the discount now needs to be large enough to compensate an impatient farmer for postponing consumption of p_{f2}, not only for incurring the utility cost f: in the case in which $y(1)$ is close to $1 + f$ (so that the return to fertilizer is just positive at a fertilizer price of 1 from an *ex ante* perspective), the discount is approximately the cost of delaying one unit of consumption for one period for an impatient person. Thus, a small discount in period 1 will have as large of an effect on ultimate fertilizer use as a large discount in period 2.

In each case, the farmers affected will be those who are patient in period 1, but impatient in period 2.

3.5 Choice of Timing of Discount

Finally, let us examine what will happen if the farmer can commit in period 0 to the date at which she gets a small subsidy. Specifically, we consider a subsidy that is large enough to induce patient period 1 farmers to purchase fertilizer immediately but not large enough to induce impatient farmers to buy fertilizer. Suppose there is some fixed discount δ and the farmer can choose either $p_{f1} = 1 - \delta$ or $p_{f2} = 1 - \delta$. The price in the other period remains 1.

Consider first the farmers who are always patient. Because the return to the period 1 investment opportunity is always positive even when it is low, those farmers will always request the subsidy in the second period. In period 1, they will save in anticipation of buying fertilizer in period 2, and will follow through on that plan.

Next, consider farmers who are always impatient. They are not planning to save or use fertilizer, so they are in principle indifferent on when to get the return. However, if there is even some small probability that they will be patient in the future, they will choose to receive the small discount in period 2, rather than refuse the program.

Finally, consider the case of the stochastically impatient farmers. If the discount does not reduce the price of fertilizer below $p^*_{f1}(R)$, then farmers will always choose to take the discount in period 2, because the discount is not big enough to induce them to buy immediately in period 1 so the only way that they will buy fertilizer is if they happen to be patient in both periods. In what follows, we consider the case in which $\delta > 1 - p^*_{f1}(R)$.

In this case, if a farmer chooses to receive the discount in period 1, her expected utility is:

$$\beta_k[x + \tilde{p}(y(1) - p_{f1} - f)] \tag{13}$$

If she chooses to receive the discount in period 2, her expected utility is:

$$\beta_k[x + \tilde{p}^2(y(1) - \frac{p_{f1}}{1+R} - f) + \tilde{p}(1-\tilde{p})p_{f2}\frac{R}{1+R}] \tag{14}$$

Note first that current impatience does not affect this decision (since farmers discount all future periods at the same rate in period 0). Second, observe that when *R* is close to zero, so long as $\tilde{p}$ does not equal zero, the farmer will chose the discount in period 1: since the period 0 farmer does not care whether the period 1 or period 2 farmer pays the utility cost, the only gain to delaying the decision is the return to the period 1 investment opportunity. However, as *R* increases, the value of delaying the discount to period 2 increases, and if *R* is high enough, the farmer will choose to receive the discount in period 2. Thus, depending on whether the returns to period 1 opportunity are high or low, the farmers will choose to receive the returns in period 1 or in period 2.

3.6 Summary

To summarize, the model gives rise to the following predictions.

1. Some farmers will make plans to use fertilizer but will not subsequently follow through on their plans.
2. Farmers will switch in and out of fertilizer use.
3. A small reduction in the cost of using fertilizer offered in period 1 will increase fertilizer purchases and usage more than a similar but unexpected reduction offered in period 2. The subsidy only needs to be large enough to compensate the farmer for incurring the decision and shopping cost up front, rather than later, as well as for the foregone returns to the period 1 investment. A larger subsidy will be needed in period 2 to induce the same increase in usage as a small subsidy in period 1.
4. When farmers are offered an *ex-ante* choice between a small discount in period 1 or the same discount in period 2, some farmers will choose the discount in period 1. Recall that for a positive *R*, time-consistent farmers would always prefer to receive the discount in period 2. Therefore, if there are farmers who choose the discount in period 1 and follow through by buying fertilizer, this suggests that some farmers are time inconsistent, and have at least some awareness of it.

4. Testing the Model

As noted above, there is some empirical evidence in favor of predictions 1 and 2: in a sample of farmers who participated in the demonstration plot program, two-thirds of those who had made plans to use fertilizer do not end up carrying through with these plans (prediction 1). We also find significant switching between using and not using fertilizer (prediction 2): a regression of usage during the main growing season on usage in the main growing season previous year (as well as a full vector of controls) gives an R^2 of only 0.25. Suri (2007) similarly finds considerable switching in and out of fertilizer use in a nationally representative sample.

Of course, we may not want to attach much weight to the declared intentions of farmers and therefore discount the evidence on prediction one. Similarly, other stories could generate switching in and out of fertilizer use. We therefore focus on predictions 3 and 4 below. Predictions 3 and 4 of the model suggest that some simple interventions could have large impacts on fertilizer use. We collaborated with International Child Support (ICS) – Africa, a Dutch NGO that has had a long-lasting presence in Western Kenya, and is well known and respected by farmers, to design and evaluate a program using a randomized design that would encourage fertilizer use if farmers did indeed behave according to the model. To test the predictions of the model, we implemented multiple versions of the program, and compared them with alternative interventions, such as a fertilizer subsidy and reminder visits.

4.1. The SAFI Program

The main program was called the Savings and Fertilizer Initiative (SAFI) program. The program was first piloted with minor variations over several seasons on a very small scale with farmers who participated in the on-farm trials described in Duflo, et al. (2008). In these pilot programs, we focused on acceptance of the program and willingness to buy from ICS. In 2003 and 2004, the program was implemented on a larger scale, and we followed farmers to determine its impact on fertilizer usage.

Basic SAFI

In its simplest form, the SAFI program was offered at harvest, and offered free delivery of any combination of planting or top dressing fertilizer. The basic SAFI program worked as follows: a field officer visited farmers immediately after harvest, and offered them an opportunity to buy a voucher for fertilizer, at the regular price, but with free delivery. The farmer had to decide during the visit whether or not to participate in the program, and could buy any amount of fertilizer. To ensure that short-term liquidity constraints did not prevent farmers from making a decision on the spot, farmers were offered the option of paying either in cash or in maize (valued at the market price). To avoid distorting farmers' decision-making by offering free maize marketing services, farmers also had the option of selling maize without purchasing fertilizer. Across the various seasons, the majority (66 percent) of those who purchased fertilizer through the program bought with cash, which suggests that maize was not overvalued in the program. Participating farmers chose a delivery date and received a voucher specifying the quantity purchased and the delivery date. Choosing late delivery would provide somewhat stronger commitment to use fertilizer since fertilizer can potentially be re-sold (at some cost) and the vouchers themselves were non-transferable.

The basic SAFI program could have reduced the utility cost of fertilizer use, and thus reduced procrastination, in two ways. First, it can save a trip to town to buy fertilizer, which is typically about a 30 minute trip from the farmers' residences. Suri (2007) argues that distance to a fertilizer provider accounts for her surprising finding that those who would have had the highest return to using fertilizer are some of the least likely to use it. Fertilizer is typically available in major market centers around the time it is needed for application for maize crops. Since most farmers travel to market centers occasionally for shopping or other errands, they could pick up fertilizer when they go to town for other reasons.[6]

Second, and more speculatively, by requiring an immediate decision during the field officer's visit and offering a simple option, the program may have reduced time spent thinking through which type of fertilizer to use, and in what quantity.

SAFI with *ex-ante* choice of timing

To test prediction 4 of the model, in the second season of the experiment, farmers were visited *before* the harvest (period 0 in our model) and offered the opportunity to decide when they wanted to be visited again later to receive a SAFI program: farmers were told that, during this visit, they would have the opportunity to pay for fertilizer and to choose a delivery date. As discussed earlier, in a standard exponential model, farmers would be expected to choose a late visit: those who want to use fertilizer would then invest in period 1, and be prepared for fertilizer purchase in period 2. If farmers were present-biased but completely naïve, they would also have chosen a late delivery date, since they expect to be patient in the future, and would then plan to invest in period 1 and purchase fertilizer in period 2. This would lead to low ultimate adoption. In our model, stochastically hyperbolic farmers whose period 1 investment opportunity has a high return also choose a late delivery date to avoid forgoing the returns of the investment, but those who have a low return investment

[6] Most farmers who bought fertilizer through the SAFI program did not buy enough that they would have had to pay for transport. On average, farmers who bought fertilizer through the SAFI program bought 3.7 kilograms of fertilizer (at a total cost of 135 Kenyan shillings), and only 1 percent of farmers bought more than 10 kilograms. It would take the average farmer roughly an hour to walk to town, buy fertilizer, and walk back. For a farmer who makes $1 a day over an eight-hour workday, the SAFI program would save her about $0.13 in lost work time, or about 10 percent of the cost of the fertilizer bought by the average farmer. This cost would be substantially smaller if the farmer were going to town anyway and so would not miss any work time.

opportunity in period 1 will chose an early delivery date, to increase the probability that they eventually use fertilizer.

4.2 Experimental Design

Two versions of the SAFI programs were implemented as part of a randomized field experiment, allowing for a test of the model. Farmers were randomly selected from a sample frame consisting of parents of fifth and sixth grade children in sixteen schools in Kenya's Busia district. The program was offered to individuals, but data was collected on all plots farmed by the households. And a farmer was considered to use fertilizer if fertilizer was used on any plot in the household.

The experiment took place over two seasons. In the first season (beginning after the 2003 short rain harvest, in order to facilitate fertilizer purchase for the 2004 long rains season), a sample of farmers was randomly selected to receive the basic SAFI program. The randomization took place at the individual farmer level after stratification by school, class, and participation in two prior agricultural programs (a program to provide farmers with small amounts of fertilizer in the form of "starter kits" they could use on their own farm, and a program to set up demonstration plots on the school property).

In the following season (the 2004 short rains), the program was repeated, but with an enriched design to test the main empirical predictions of the model in Section 3 as well as some predictions of alternative models. All treatment groups were randomized at the individual level after stratification for school, class, previous program participation, and 2003 treatment status.

First, a new set of farmers was randomly selected to receive a basic SAFI visit. Second, another group of farmer was offered SAFI with *ex ante* choice of timing (as described above).

Third, to test the hypothesis that small reductions in the utility cost of fertilizer have a bigger effect if offered in period 1, another group of farmers was visited close to the time fertilizer needs to be applied for top dressing (approximately 2 to 4 months after the previous season's harvest, the equivalent of period 2 in our model), and offered the option to buy fertilizer with free delivery. To calibrate the effect of a discount, a fourth group of farmers was visited during the same period, and offered fertilizer at a 50 percent discount. This allows us to compare the effect of a 50 percent subsidy to the effect of the small discount offered by the SAFI program. In all of these programs, farmers could choose to buy either fertilizer for planting, top dressing, or both. However, one caveat to bear in mind is that in the late visits many farmers had already planted and could only use top dressing fertilizer in that season. If farmers preferred using fertilizer at planting, however, they could have bought planting fertilizer for use in the next season, so a standard model would suggest that these farmers should have taken advantage of the discount for later use.

Finally, in each of the intervention groups as well as in the comparison group, a random subset of farmers was offered the option to sell a set quantity of maize at a favorable price to the field officer before the program took place. The objective of this additional treatment was to test the alternative hypothesis that the SAFI program was just seen by the farmers as a safer way to protect their savings than available alternatives. The purchase of maize put some cash in the hands of the farmers who accepted the offer, which is more liquid than maize, and thus arguably easier to waste. If the main reason why farmers purchased fertilizer under the SAFI program is because of an aversion to holding liquidity, the purchase of maize should have encouraged them to take SAFI up. Under our model, this would make no difference, however.

Appendix figure 1 summarizes the experimental design for this second season.

4.3 Data and Pre-Intervention Summary Statistics

The main outcome of interest is fertilizer use, with fertilizer purchase through the program as an intermediate outcome. We have administrative data from ICS on fertilizer purchase under the program. Data on fertilizer use was collected at baseline (before the 2003 short rains harvest) for that season and for the previous season. We later visited farmers to collect fertilizer usage data for the three seasons following the first SAFI program (i.e., both seasons in 2004 and one season in 2005). The baseline data also included demographic information and some wealth characteristics of the sampled households. In households where different members farm different plots (which is typically the case in polygamous households), we asked each member individually about fertilizer use on her own plot, and we asked the head of the household (the husband) about fertilizer use on each plot. The data is aggregated at the household level.

Table 1 shows descriptive statistics. In season one, 211 farmers were eligible to participate in the basic SAFI program, and 713 farmers constituted a comparison group. In season two, 228 farmers were eligible to participate in the basic SAFI program; 235 were eligible for the SAFI with *ex ante* choice of timing; 160 were offered fertilizer at the normal retail price with free delivery at top-dressing time; and 160 were offered fertilizer at half price with free delivery at top dressing time. An additional 141 farmers served as a comparison group.

There were some relatively minor pre-treatment differences between groups in each season. In season one 43 percent of both SAFI and comparison groups had previously ever used fertilizer. However, there were some pre-treatment differences in other observables: comparison group farmers had 0.6 more years of education (a difference significant at the 10 percent level), and were about 5 percent less likely to live in a home with mud floors, mud walls, or a thatch roof (though only the difference in the probability of having a mud floor is statistically significant, at 10 percent).[7]

In season two, the comparison group was more likely to have used fertilizer prior to the program (table 1, panel B). The point estimate for previous fertilizer usage is 51 percent for the comparison group, but only between 38 percent and 44 percent for the various treatment groups. Many of these differences are significant at the 10 percent level (the difference is significant at 5 percent for the 50 percent subsidy group). In addition, the comparison group has significantly (at 10 percent) more years of education than the group offered SAFI with the *ex ante* timing choice.

These pre-treatment differences are in general relatively minor and would, if anything, bias our estimated effects downwards. We present results with and without controls for variables with significant differences prior to treatment—in all cases, the inclusion of these controls does not substantially affect our results.

5. Results

5.1 The SAFI Program

The SAFI program was popular with farmers. In season one, 31 percent of the farmers who were offered SAFI bought fertilizer through the program. In season two, 39 percent of those offered the basic version of SAFI bought fertilizer through the program, as did 41 percent of those offered SAFI with *ex ante* choice of timing. The fraction of farmers who purchase fertilizer is of course not equal to the impact of the program on use: some program farmers

[7] Appendix table 1 suggests that attrition patterns were similar across groups. Regressions of indicators for appearance in the pre-treatment background and post-treatment fertilizer adoption questionnaires on being sampled for treatment yield no significant differences between groups. Overall, 1,232 farmers were sampled, and we obtained adoption data for 925 of them (75.1 percent). There were few refusals. Nearly all of those who do not appear in the dataset were not known by other parents in the school and so could not be traced, or were not at home when ICS enumerators visited their homes.

who were going to use fertilizer anyway presumably bought fertilizer through SAFI, to take advantage of the free delivery. In addition, some farmers may not have used fertilizer purchased through SAFI on their maize crop: they could have kept it, sold it, used it on some other crop, or the fertilizer could have been spoiled. In the 2005 adoption questionnaire 76.6 percent of the farmers who purchased fertilizer under SAFI reported using it on their own plot, 7.3 percent on the plot of their wife or husband, and 8.1 percent reported saving the fertilizer for use in another season. The remainder reported that they had used the fertilizer on a different crop (1.6 percent) or that the fertilizer had been spoiled.

Overall, in both seasons, the SAFI program had a significant and fairly sizeable impact on fertilizer use. In season one 45 percent of farmers offered the SAFI program report using fertilizer in that season, compared to 34 percent of those in the comparison group.[8] The 11 percentage point difference is significant at the 1 percent level (see table 1, panel A). In season two (the 2004 short rains), the basic SAFI program increased adoption by 10.5 percent (table 1, panel B).

Table 2 confirms these results in a regression framework. For season one, we run regressions of the following form:

$$y_i = \alpha + \beta_1 T_{1i}^{LR} + X_i' \gamma + \epsilon_i \qquad (15)$$

where y_i is a dummy indicating whether the household of farmer i is using fertilizer, ${T_1}_i^{LR}$ is a dummy indicating whether farmer i was offered the SAFI program in season one, and X_i is a vector of control variables for the primary respondent in the household, including the school and class from which the parent was sampled, educational attainment, previous fertilizer usage, gender, income, and whether the farmer's home has mud walls, a mud floor, or a thatch roof, and whether the farmer had received a starter kit in the past.[9] The table presents fertilizer usage statistics for the season of the program and the two subsequent seasons.

Both specifications suggest a positive and significant program impact on fertilizer adoption in season one: the specification with sparser controls suggests that the program led to an 11.4 percentage point increase in fertilizer adoption, while one with fuller controls

[8] Throughout this paper, we focus on usage of fertilizer rather than the quantity of fertilizer used because there is substantial underlying variation in the quantity of fertilizer used by farmers, which would make it difficult to pick up effects in average quantities. The standard deviation in kilograms of fertilizer used is 54, whereas farmers that bought fertilizer through the SAFI program bought only 3.7 kilograms, on average.

[9] The starter kit was an intervention conducted in a previous season, which we discuss in a companion paper. It involved distributing a small quantity of fertilizer to farmers to let them experiment with fertilizer.

suggests a 14.3 percentage point increase. Both are significant at the 1 percent level. Given a baseline usage rate of 22.8 to 24.7 percent (shown on the last row of table 2), these effects represent a 46 to 63 percent increase relative to the comparison group.

The remaining columns show that the SAFI program does not have persistent impacts: in the two subsequent seasons (the short rains of 2004 and the long rains of 2005), fertilizer usage drops back to the level of the comparison group. This lack of persistence would be expected under our model since the only role of SAFI in this program is to induce the farmer to buy the fertilizer early in the season, rather than later. In contrast, in learning by doing models, and models of credit constraints, inducing use in one period would in general affect the state variables of wealth and knowledge and thus future behavior.

Panel B shows the impact of the SAFI program in the second season on fertilizer usage. The regression has the same form as for the season one regression, but includes dummies for all the other SAFI treatments, and controls for a dummy for long rains treatment status ($T1_i^{LR}$):[10]

$$y_i = \alpha + \sum_{k=1}^{4} \beta_i^{SR} T_{ki}^{SR} + \beta_5 B_i^{SR} + \beta_6 B_i^{SR} T_{1i}^{SR} + X_i' \gamma + \epsilon_i \tag{16}$$

In this regression, $T1_i^{SR}$ represents the basic SAFI program, and $T2_i^{SR}$ through T_{4i}^{SR} represent the other treatment groups, respectively, SAFI with *ex ante* choice of timing; the visit at top-dressing time that offered fertilizer at full price; and the visit at top-dressing time that offered fertilizer with a 50 percent subsidy. The dummy B_i^{SR} is a dummy equal to 1 if the farmer was offered the opportunity to sell maize at an above-market price during the post-harvest visit. As before, we present regressions with and without full sets of controls, for season 1 (the season before the programs were offered), season 2 (the season during which the programs were offered), and season 3 (one season after the programs were offered).

The first row in panel B, columns (3) and (4) show the impact of the basic SAFI program on adoption of fertilizer in the season it was offered. Without control variables, the point estimate for the effect (16.5 percentage points) is even larger than in the first season. Since, as we saw earlier, adoption was slightly greater in the comparison group before the program was introduced, the point estimate of the effect increases slightly when controlling for past adoption to 18.1 percentage points. Given a baseline usage rate of 29.7 to 30 percent in the comparison group, these effects represent proportional increases of 56 to 60 percent.

[10] Treatment was stratified by prior treatment status.

Columns (1) and (2) show that, reassuringly, there is no difference in adoption across SAFI groups in the season before it was offered. Columns (5) and (6) replicate the results found for the first season: the impact of the SAFI program is not persistent.

These results suggest that a properly timed reduction in the utility cost of using fertilizer can substantially increase adoption. Free delivery saves the farmer a trip to the nearest market town to get the fertilizer and, since taking advantage of free delivery required deciding on the type and quantity of fertilizer to order during the visit, the program may have reduced the cost of time spent making these decisions and thus the chance of procrastination on those costs. It is therefore plausible that the reason why this program increased adoption is time inconsistency and procrastination as posited in the model.

The model predicts that those stochastically hyperbolic farmers who do not have a high return period 1 investment opportunity will request early delivery. The results for the SAFI with *ex ante* timing choice are consistent with the idea that a sizeable fraction of farmers have a preference for commitment. Almost half of the farmers (44 percent) offered SAFI with timing choice asked the field officer to come back immediately after harvest, and 46 percent of those actually bought fertilizer. Of the remaining farmers, 52 percent requested late delivery and 39 percent of those who requested late delivery eventually purchased fertilizer; the remaining 4 percent declined to participate in the SAFI program. These results are very much consistent with the model, which predicts that as long as $\tilde{p} > 0$, even quite naïve farmers may want to induce their period 1 selves to purchase fertilizer by requesting the offer of free delivery early unless they have a high return to their period 1 investment opportunity. In contrast, time consistent farmers who attach any probability to using fertilizer would never choose a period 1 discount (so long as the returns to investment are positive).

If the parameters are such that farmers with high return investment opportunities prefer late delivery, our model predicts that fewer farmers should end up using fertilizer under SAFI with choice of timing then under the basic SAFI, in which free delivery is restricted to period 1. This is because the stochastically hyperbolic farmers with high returns to the period 1 investment opportunity buy fertilizer in period 1 under the basic SAFI, but choose a period 2 discount under SAFI with timing choice, and some of those choosing a late delivery date wind up impatient in period 2 and do not buy fertilizer. Empirically, we find that the impact of the "SAFI with *ex ante* timing choice" on fertilizer use is if anything slightly larger than the basic SAFI program. Overall, 41 percent of farmers purchased fertilizer under SAFI with *ex ante* timing choice (compared to 39 percent without timing choice), and more farmers reported using fertilizer under SAFI with *ex ante* timing choice (47 percent versus 38 percent), although these differences are not significant (see the second row of panel B, table 2).[11]

Note, however, the fact that the effect of the SAFI with *ex ante* choice of timing is as large as the effect of the basic SAFI helps rule out an alternative explanation for the popularity of basic SAFI: an "impulse purchase" effect in which when farmers are offered fertilizer at harvest, when they have money and maize, they feel "flush" and buy it without thinking, as an impulsive purchase (under this hypothesis, if the field officers had offered beer or dresses at that point, they would have bought those). This seems reasonable given that the pre-harvest season is known as the "hungry season" in Kenya, and the field officer does not offer to sell the farmer anything immediately in the SAFI with *ex ante* timing choice. Instead, the field officer offers an opportunity to buy fertilizer in the future: thus, the decision on when to call the field officer back is unlikely to be an impulsive decision.

Another piece of evidence suggesting that the purchase of fertilizer is not simply an impulse purchase of farmers who feel "flush" is that farmers were no more likely to purchase fertilizer under SAFI when they had cash on hand. To test this, we ran a small test in which the field officer offered to purchase some maize at a favorable price before offering SAFI. Under this condition, while 50.7 percent of farmers sold maize, 36 percent still purchased fertilizer under SAFI, and thus the effects of the "bought maize" dummy on fertilizer use, as well as its interaction with the SAFI dummy, are insignificant and small. This also helps rule out the possible alternative explanation that SAFI is used by farmers as a safe savings option: if this were the case, one would have expected them to be more likely to take advantage of SAFI when they had cash on hand.

Thus, the impact of the two versions of the SAFI suggest that time inconsistency and procrastination may play a role in explaining low fertilizer use. To rule out alternative

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[11] A possible interpretation for the larger effect of SAFI with timing choice is that stochastically hyperbolic farmers may differ in their discount rates. In the model, we assume that impatient farmers will never use fertilizer and that all patient farmers value the return to fertilizer higher than their alternative period 1 investment opportunity (even if the return to that investment is high). However, it may be that some farmers may be (stochastically) intermediately patient (with a discount rate between β_L and β_H) and will commit to fertilizer purchase in period 1 only if their period 1 investment has a low return, if they happen to be intermediately patient in period 1. These farmers will only use fertilizer if they end up being patient (or intermediately patient) in period 2, and so will request a late SAFI date and will never buy fertilizer in the basic SAFI but may buy in the SAFI with timing choice. Another possibility is that by warning farmers in advance, we give them a bit more time to be ready with cash when the field officer arrives.

explanation of the role SAFI played in inducing farmers to use fertilizer, we tried two alternative programs with random subsets of farmers, which allow us to test alternative hypotheses and additional predictions of the model.

5.2. Free Delivery, Free Delivery with Subsidy

Both versions of the SAFI program offered free delivery. Our interpretation is that the resulting decrease in the utility cost of using fertilizer is small enough that it would be unlikely to induce large changes in fertilizer use in a purely time-consistent model. However, an alternative explanation is that the free delivery is a substantial cost reduction. To test this hypothesis, and to test prediction three in our model, we offered free delivery later in the season (corresponding to period 2). We also offered a 50 percent subsidy to a separate, randomly selected group of farmers at the same point in the season.

As shown in table 1, panel B, free delivery later in the season did not lead to fertilizer purchases from ICS as often as under the SAFI program (20 percent under free delivery vs. 39 percent in the SAFI). The difference between the fraction of farmers who purchase fertilizer under free delivery late in the season and any of the other groups is significant at the 1 percent level, while all the other groups have similar levels of adoption. When offered a 50 percent subsidy late in the season, 46 percent of farmers bought fertilizer.[12]

Table 2 (columns 3 and 4) presents the impacts of the different programs on fertilizer use, and shows very consistent results: the offer of free delivery late in the season increased fertilizer use by 9 to 10 percentage points (not significant), less than half the increase due to the SAFI program (or SAFI with *ex ante* timing choice). Our model predicts that free delivery late in the season will have no adoption impact, since those farmers who are patient and take up this offer would have bought fertilizer on their own anyway (so purchase with free delivery would entire crowd out purchases that would have happened anyway). Indeed, we cannot reject the hypothesis that the program had no effect, although the positive point

[12] As mentioned earlier, one issue when interpreting these results is that fertilizer can be used either at planting or at top dressing (when the plant is knee high), or both. Since farmers in the subsidy and full price groups were visited after planting, it was too late for them to buy planting fertilizer for use in that season (however, while very few of the farmers who were offered fertilizer at full price at top dressing bought planting fertilizer, 17 percent of the farmers offered the subsidy actually bought planting fertilizer—presumably to either sell it or use it in a future season. By contrast, SAFI farmers could choose between planting and top dressing fertilizer, or could get both. This would complicate interpretation of the comparison between the programs if fertilizer at top dressing were not effective. However, our earlier estimates (Duflo, Kremer, and Robinson, 2008) suggest that the average rate of return to using fertilizer at top dressing only is 70 percent. We view the decision between using fertilizer at planting rather than top dressing as a timing decision similar to when to buy.

estimate may suggest that there may exist some people who are at an intermediate level of patience, for whom free delivery is sufficient to induce fertilizer use. Importantly, however, the difference between the percentage point increase due to SAFI and the percentage point increase due to free delivery is significant at the 8 percent level. Thus, we can reject that the timing of the offer does not matter.

Interestingly, a 50 percent subsidy in period 2 significantly increases fertilizer use (by 13 to 14 percentage points), which is very similar to the impact of the free delivery at harvest time (and statistically undistinguishable). This is consistent with prediction three of the model.

6 Calibration and Welfare Comparisons

In this section we calibrate the model to determine the fraction of farmers who are stochastically hyperbolic, the probability that they are patient each period, and the proportion of stochastically hyperbolic farmers who have a high return to the period 1 investment and so choose to take SAFI at a later date. We then show that the calibrated model yields reasonable predictions for the fraction of farmers who never use fertilizer and for ultimate fertilizer usage among farmers who choose early and late delivery when given *ex ante* timing choice under SAFI. Finally, we use the calibrated model to compare welfare between laissez faire, heavy Malawian-style subsidies, and small, time-limited discounts.

6.1 Calibrating the Model

Recall that a fraction γ of farmers are always patient and always use fertilizer and a fraction ψ of farmers are always impatient and never use fertilizer.[13] The remaining fraction $1-\gamma-\psi=\phi$ of farmers are stochastically hyperbolic (as described above), and patient in any period with probability p.

To solve for the parameters of the model, note that the model implies that the fraction of farmers using fertilizer without the SAFI program is $\phi p^2+\gamma$ (since stochastically hyperbolic farmers use fertilizer only if patient in both periods 1 and 2). Taking the average comparison group usage from the two SAFI seasons in Table 2, this quantity is about 0.27 (Columns 1-4).

Under SAFI, all stochastically hyperbolic farmers who are patient in the first period will use fertilizer, as will all time-consistent farmers. Hence the proportion of farmers using fertilizer will be $\phi p + \gamma$. Using the regression-adjusted estimates with full controls in table 2, this percentage is about 0.44 in our dataset.

A third equation gives the percentage of non-program farmers that we would expect to find using fertilizer in the three seasons that we follow them. This percentage is given by $\gamma + \phi(p^2)^3$, and is equal to 0.16 in our dataset. Solving these equations gives us that $p = 0.40$, $\phi = 0.71$, $\gamma = 0.16$, and $\psi = 0.13$.

These estimates are in line with our finding that 52 percent of comparison farmers do not use fertilizer in any season in which we observe them (we followed farmers for three years after the first SAFI). Given the parameters above, we would predict that $\psi + \phi(1 - p^2)^3 = 0.13 + 0.71 * .84^3 = 0.55$ of farmers would not use fertilizer in those three seasons.

Note that these estimates were derived solely from data on average use with and without SAFI, not from looking at the correlation in fertilizer use over time, so this provides a first piece of evidence on the fit of the calibration.[14]

Another check of the model is the fraction of farmers who end up using fertilizer under the 50 percent subsidy. If a 50 percent subsidy is enough to induce stochastically impatient farmers who were patient in period 1, but impatient in period 2, to use fertilizer, the fraction of farmers using fertilizer under a 50 percent subsidy in period 2 should be $\phi p + \gamma$ which, we have seen, is 44 percent (since the same formula gives us the fraction of farmers who use fertilizer under SAFI). Empirically, the fraction is exactly 44 percent in our data set (see table 2).

To calibrate λ, the proportion of farmers with a high-return period 1 investment opportunity, note that under the model, if the value of the discount is large enough to induce those with low-return period 1 investments to choose early delivery but not to induce those with high-return investments to do so, then a proportion $(1 - \lambda)\phi$ of farmers choose early delivery and the remainder ask for late delivery. We therefore set $\lambda = 0.35$, since 96 percent

[13] An alternative interpretation is that these farmers have land that is not suitable for fertilizer. Note that under this interpretation, heavy subsidies would be less attractive, because such subsidies could lead these farmers to use fertilizer even if the social planner would not do so.

[14] It should be noted, however, that the model cannot match the large percentage of farmers who report having never used fertilizer. One possible reason for this is that farmers may forget if they had used fertilizer long in the past.

of those offered SAFI with timing choice accepted it, and 44 percent of those offered it chose early delivery.

The model implies that $\frac{\gamma+\lambda\phi p^2}{\gamma+\lambda\phi+\psi} = 37\%$ of those choosing late delivery would end up actually buying fertilizer. In reality, 39 percent did. This again suggests that the model does reasonably well in matching statistics that were not used to calibrate it.

Similarly, since the model predicts that the only farmers who will request early delivery will be the stochastically hyperbolic farmers who prefer committing immediately to saving, we would expect that a proportion $p = 40\%$ of farmers requesting early delivery will eventually purchase. This is very close to the actual percentage of 46 percent.

The model does a bit less well predicting the adoption impact of the SAFI with *ex ante* timing choice. We would predict that $\phi(\lambda p + (1-\lambda)p^2) + \gamma = 38\%$ would end up using fertilizer in this variant (less than the basic SAFI), whereas in reality 47 percent did (more than the basic SAFI). Although 38 percent lies in the confidence interval of our point estimate, it is further from our calibrated estimate than the other figures.

Finally, one other check on the plausibility of the estimation is whether it implies implausibly low discount rate of impatient farmers, β_L. The condition for an impatient farmer to not use fertilizer is $\beta_L(1-f) > y$. Since the mean rate of return to fertilizer is 36 percent (Duflo, Kremer, and Robinson, 2008), this implies that for f close to 0, $\beta_L \leq 0.73$. This estimate is similar to an estimate from Laibson, et al. (2007), who estimate a β around 0.7.

6.2 Laissez Faire, Heavy Subsidies, or Nudges?

The calibrated model can be used to provide a rough comparison of the welfare impacts of laissez fair, heavy subsidies, and small nudges (this is similar in spirit to the exercise carried out in Similar to the approach in O'Donoghue and Rabin (2006), to evaluate optimal taxes when a fraction of agents are not fully rational). For this calculation, we assume that *f* is small (effectively zero). We assume that the marginal cost of government funds is 20 percent[15] and consider a two-thirds subsidy similar to that adopted in Malawi. We also use estimates from the experiments described in Duflo, et al. (2008), which imply that the incremental return to a

[15] Warlters and Auriol (2005) estimate a marginal cost of public funds of 17 percent in Sub-Saharan Africa. Kleven and Kreiner (2006) report similar estimates for OECD estimates. The marginal cost of public funds could be substantially higher, depending on the choice of taxes implemented and other parameters (i.e., Ballard and Fullerton, 1992).

second unit of fertilizer is -55 percent at market prices, but about 30 percent under a two-thirds subsidy.

Under the model, a two-thirds subsidy will induce all farmers to use fertilizer but will cause patient farmers to use two units of fertilizer. Unfortunately, we cannot test this prediction directly: farmers who do not intend to use fertilizer might buy fertilizer and then resell it since heavy subsidies would be sufficient to cover the transaction costs. Moreover, it might take time for farmers to adjust to using two units of fertilizer if they need to build up assets gradually over time due to credit constraints or they need time to learn about the return to a second unit of fertilizer.

We assume that only patient farmers (the always patient farmers and those stochastically hyperbolic farmers who end up being patient in both periods) will use two units of fertilizer at a two-thirds subsidy (as discussed below, if even impatient farmers use two units of fertilizer under a two-thirds subsidy, heavy subsidies would yield even lower welfare). These categories comprise a proportion $0.16 + 0.71 * .4^2 = 27\%$ of farmers. The remaining 73 percent use one unit of fertilizer.

To compare welfare under laissez faire, heavy subsidies, and small, time-limited subsidies, we first normalize welfare under laissez faire to zero, and then calculate the costs and benefits of heavy subsidies and small, time-limited subsidies relative to laissez faire. With a 20 percent marginal cost of funds, the deadweight loss cost of financing a two-thirds fertilizer subsidy will be 0.2*0.67*[2*0.27+0.73] = 0.170. The deadweight loss from farmers inefficiently using a second unit of fertilizer is 0.27*0.55 = 0.149. Overall, heavy subsidies therefore cost 0.319 relative to laissez faire.

The benefit of this subsidy is $(y - 1 - f)(\psi + \phi(1 - p^2))$, where the first term is the benefit from the first unit of fertilizer and the second term is the proportion of farmers who would not use fertilizer without the subsidy. If we use 1.36 for y (Duflo, et al., 2008), then for $f = 0$, we get a benefit of 0.36*0.73=0.26. For the particular parameter values we examine, the costs of heavy subsidies relative to laissez faire exceed their benefits, but this conclusion will clearly be sensitive to assumptions on parameters.

By contrast, the SAFI program described in this paper provided farmers a much smaller, time-limited discount, arguably worth less than 10 percent of the cost of fertilizer. Since SAFI would be taken up by the 16 percent of farmers who always use fertilizer and the stochastically hyperbolic farmers who are patient in period 1, the total deadweight cost incurred in financing these subsidies is therefore $0.1 * 0.2(\gamma + p\phi) = 0.009$. In addition, there is a further loss of $(\gamma + p\phi)(\lambda\overline{R} + (1-\lambda)\underline{R})$ from farmers inefficiently forgoing the period 1 investment opportunity. This is unlikely to be large for many farmers, as few farmers are likely to have high return investments that yield liquid returns over the short period between one harvest and the time fertilizer is needed for top dressing (only a few weeks). Also note that if some farmers have very high rates of return investment opportunity, they would not take up SAFI. The benefit would be $(y - 1 - f)(\phi(p - p^2))$, which is equal to 0.06. Overall, in this specific example, SAFI is likely to yield higher welfare than either a laissez faire or heavy subsidy approach under reasonable assumptions about *R*.

Note that the parameter values we have chosen for this calculation are ones that are most favorable to heavy subsidies. The impact of heavy subsidies would look worse: (1) if the marginal cost of public funds is higher than 20 percent in developing countries or if providing subsidies encourages costly rent-seeking, (2) if subsidies induce impatient farmers to overuse fertilizer, (3) if the never patient farmers in our model actually have land that is unsuitable to fertilizer such that the returns to fertilizer are lower for them than for other farmers, (4) if overusing fertilizer has additional environmental costs, or (5) if even heavy subsidies do not induce the never patient to adopt fertilizer.

It is important to note that we have not considered the whole spectrum of potential policies in our calibrated model. We have obviously examined only one particular level of heavy subsidy, and other levels might perform better. In our simple two-type model a perfectly informed policymaker could potentially choose a level of subsidy just sufficient to induce impatient farmers to use one unit of fertilizer while not inducing patient farmers to overuse fertilizer. However, this result would not be robust to more complicated heterogeneity in patience or continuous choice of fertilizer quantity. Time-limited discounts are likely generically more robust than heavy subsidies, in that the losses from time-limited subsidies are likely to be limited, while heavy subsidies run the risk of seriously distorting fertilizer use and incurring large deadweight losses from taxation.

Another conclusion that seems likely to be generic is that small, time-limited subsidies are likely to be preferable to a laissez-faire policy for a wide range of parameter values, so long as there exists even a small proportion of procrastinating farmers. On the other hand, with sufficiently many stochastically hyperbolic farmers, and sufficiently few always-patient farmers, heavy fertilizer subsidies become more attractive.

The "heavy subsidy" policy could be made more attractive by limiting the quantity of fertilizer available to each farmer. Doing this would help avoid overuse of fertilizer and would also help address the problem of high fiscal costs of heavy subsidies because people would use lower quantities. Another potential policy would be to provide farmers with bank accounts that could allow them to "soft commit" to fertilizer but would not force farmers to completely tie up their money, for instance by making money available in case of other emergencies. The transactions costs of such accounts would fall in an intermediate category—far less liquid than holding cash on hand, but more liquid than reselling fertilizer that has already been purchased. To the extent that liquidity is valuable, these types of bank accounts could be preferable to a targeted discount.[16]

7 Alternative Explanations

The empirical results in this section are consistent with the predictions of the model in section 2. We now review three alternative models that could have similar qualitative predictions, and report additional evidence on whether these models can explain the data.

7.1 Farmers are Time-Consistent but the Utility Cost of Using Fertilizer is Large

An alternative explanation for the large impact of the free delivery of fertilizer is that farmers are time-consistent, but the fixed cost of acquiring fertilizer is high, so fertilizer is only worth purchasing in large enough quantities that credit constraints bind. In this case, free delivery of fertilizer from a trusted source may increase purchase substantially.

Under this alternative model, free delivery later in the season would increase usage as much as free delivery at harvest *if the free delivery were announced in advance*. Prior to implementing the full scale SAFI program described above, ICS conducted a number of small pilot SAFI programs with farmers who had previously participated in demonstration plots on their farms (see Duflo, Kremer, and Robinson (2008) for a description of the demonstration plot programs). Three randomly assigned variants were conducted in different seasons in different villages, each with its own comparison group. Farmers were always informed about the program immediately after harvest, but the timing of the free delivery differed across years. In the first variant, pilot SAFI program farmers were asked to pay for the fertilizer right away (as in the basic SAFI program). In the second variant, farmers were informed about the program, asked whether they wanted to order fertilizer, and given a few days before

[16] Accounts similar to these are being implemented in Malawi by Xavier Giné, Jessica Goldberg, and Dean Yang.

the field officer returned to collect the money and provide the voucher. The third variant was similar, but the field officer only went back to collect the money just before planting.

For the three pilot SAFI programs, data is available only on purchase under the program, not on eventual fertilizer use. Results are presented in table 3. In all the versions of the program, between 60 percent and 70 percent of the farmers initially ordered fertilizer. These rates are substantially higher than under the full-scale SAFI program, most likely because these were farmers with whom ICS had been working intensely for several months and because in the pilot SAFI, the field officer harvested with the farmer and SAFI was offered on the very day of the harvest. In the full-scale version of the SAFI program, the visit took place in the week following the harvest. When the field officer did not immediately collect the payment, fertilizer purchase falls significantly: from table 3, when farmers are given a few days to pay, the fraction who actually purchase fertilizer falls from 64 percent to 30 percent; when they are given a few months, purchase falls to 17 percent. These differences in purchase rates remain significant when controlling for various background characteristics.

These different SAFI programs were conducted in different villages. To confirm that the SAFI options themselves, rather than other differences, explain the differential take-up results, 52 farmers in the same schools were offered the three options in the same season. Though the sample size is small, the results follow the same stark pattern: among farmers who had to pay for fertilizer the day after the harvest, 47 percent purchased fertilizer. Among farmers who had to wait a few days to pay, 47 percent of farmers initially ordered fertilizer, but only 29 percent eventually purchased fertilizer. Among farmers who had to wait several months to pay, 50 percent initially made an order but none eventually purchased fertilizer. While this extreme result is probably not representative of what would happen in a larger sample, the sharp decline across the options is evident.

7.2 Farmers are Fully Sophisticated, but Resale of Fertilizer is Possible

Another alternative hypothesis is that farmers are stochastically hyperbolic (as in our model) but fully sophisticated. Since these farmers fully anticipate the probability that they will be impatient in the future, they would like to tie their hands even in the absence of SAFI—in particular, these farmers could buy fertilizer at the harvest on their own and hold it until it is needed. However, if resale of fertilizer is possible, with reasonably high probability these farmers may end up being so impatient in the future that they will sell the fertilizer to increase consumption. If these farmers buy fertilizer, they would pay a purchase cost f in period 1, and a resale cost in period 2, but would still end up without fertilizer. Anticipating this, fully sophisticated farmers who are patient in period 1 may prefer to delay buying fertilizer until period 2 to see if they are still patient, rather than to buy in period 1 and risk incurring resale costs.

Data on the choice of delivery time under the basic SAFI program provides some evidence against this hypothesis. Recall that when farmers purchased vouchers through SAFI, they chose a date on which the fertilizer would be delivered by the NGO. Therefore, farmers could only receive fertilizer at the pre-chosen delivery date.[17] This feature was introduced precisely to be useful to farmers needing a strong commitment. Under the hypothesis above, patient sophisticated farmers would take advantage of the SAFI program to lock up resources to protect them from impatient period 2 farmers by requesting delivery just before the time that fertilizer needs to be applied. In practice, however, about 90 percent of farmers requested almost immediate fertilizer delivery (this could be because they thought there was some hazard rate of ICS bankruptcy or because they wanted to keep the flexibility of selling back the fertilizer in case of a serious problem, but in any case, there does not seem to be strong motivation to guard against resale by future selves). Furthermore, the evidence suggests that almost nobody sold the fertilizer after buying it. While our data is from self-reports, and the farmers may have felt bad admitting to the field officer that they re-sold the fertilizer, field officers were very careful to emphasize to farmers that this was not a subsidy program, and that the farmers were free to do whatever they wanted with the fertilizer they bought under the program. Of farmers that bought through the SAFI program, 84 percent of the farmers report having used the fertilizer on their plot or that of a spouse, 8.1 percent still had the fertilizer and planned to use it in another season, and 1.6 percent of farmers reported that the fertilizer had been spoiled. Thus, unless farmers lied about fertilizer use, the upper bound on the fraction re-sold is probably 6 percent. This suggests that while selling fertilizer is possible in theory, this is probably sufficiently costly in practice, and involves sufficient time delays and fixed costs of searching for buyers that even impatient period 2 farmers do not think it is worthwhile.

Further evidence against the hypothesis that the main benefit of the program for farmers was the opportunity of strong commitment it offered comes from the farmers from whom an ICS field officer offered to purchase some maize at a premium price at the very beginning of the SAFI visit (this program was described above). Since cash is more liquid than maize, farmers might particularly want to get strong commitment when they have cash on hand. However, as discussed above, farmers who were asked to sell their maize were no more likely to take up the SAFI program than other farmers.

7.3 Farmers are Absent-Minded

Another possible alternative explanation is that while farmers are aware of their own time inconsistency problems, they deal with so many competing pressures and issues that they simply do not remember to buy fertilizer early in the season even when they know they should (see, for instance Banerjee and Mullainathan, 2008b). Under this hypothesis, the field officer's visit acts as a reminder to stochastically impatient farmers who happen to be patient in period 1 to buy fertilizer while they are still patient.

A "reminder" intervention provides little support for this explanation. During collection of post-treatment adoption data in 2005 (two seasons after the initial SAFI treatment, and one season after the second), field officers visited farmers right after harvest (at the same time the SAFI intervention would normally be conducted), and read farmers a script, reminding them that fertilizer was available at nearby shops and in small quantities, and that we had met many farmers in the area who had made plans to use fertilizer, but subsequently did not manage to implement them. The field officer then urged the farmers to buy fertilizer early if they thought they were likely to have this problem (note that this intervention would also increase fertilizer take up under our model if it raised $\tilde{p}$, making farmers more aware of their time inconsistency problem). To measure the impact of the intervention, field officers surveyed farmers at the time of top dressing for the following season to determine if they had purchased fertilizer or planned to. The reminder intervention did not significantly affect whether the farmers either bought or planned to buy top dressing fertilizer by the time they were surveyed (see table 4).

8. Conclusion

In earlier work (Duflo, et al., 2008) we presented evidence that fertilizer is profitable in Western Kenya but many farmers do not use it. Though several factors likely contribute to this,[18] the model and evidence in this paper suggests behavioral factors likely play an important role.

[17] Farmers could also come to the ICS office if they lived near town, but in practice very few farmers did this.

[18] In particular, demonstration plot experiments suggested that many farmers who do not currently use fertilizer do not know how much to use, and would likely have low or negative return if they used as much as they think

Our model suggests small, time-limited discounts can potentially help present-biased farmers overcome procrastination problems, while minimally distorting the investment decisions of farmers who do not suffer from such problems. Empirically, small, time-limited reductions in the cost of purchasing fertilizer at the time of harvest induce substantial increases in fertilizer use, comparable to those induced by much larger price reductions later in the season.

A policy of small, time-limited subsidies may therefore be attractive. It would increase fertilizer use for present-biased farmers, but would create minimal distortions in behavior of farmers who were not present-biased. It would thus presumably be environmentally more attractive than heavy subsidies, and would not encourage heavy rent-seeking as large subsidies might. One important caveat is that this policy of small, time-limited discounts does not achieve the first best from the perspective of a hypothetical period zero farmer, since farmers who are impatient in period 1 will not take advantage of such a discount. Indeed, it is worth noting that while the SAFI program boosted fertilizer use substantially from pre-existing levels, take-up remained quite low.

Calibration suggests that small, time-limited subsidies are likely to yield higher welfare than either heavy subsidies or laissez faire. However, that calibration ignored the administrative and staff costs of implementing either type of program. With those costs figured in, the SAFI program itself, with its delivery of small quantities of fertilizer to farmers by field officers, is too expensive (in terms of staff costs) to be cost effective and therefore could not be directly adopted as policy. However, preliminary results from a pilot program designed to mimic key elements of SAFI without individual free delivery (and thus expensive visits to farms) suggest that time-limited coupons for small discounts on fertilizer could cost effectively increase take-up. During school meetings, coupons for a reduction of 6 Kenyan shillings (17 percent) in the price of up to 5 kilograms of fertilizer were distributed to 94 parents (there was no comparison group). Coupons had to be redeemed at a set of identified shops in the region within 10 days, and field officers observed fertilizer sales in these selected location to ensure that the coupons were actually redeemed by farmers. Overall, 31 percent of farmers who received the coupon purchased fertilizer (most of them at

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they should. Furthermore, it seems likely that there are important barriers to social learning in this environment, since demonstration plots led to significant increases in adoption (presumably due to informational effects) but no spillover to geographical neighbors or agricultural contacts.

the end of the ten-day period). Though the absence of a control group makes it impossible to know whether the program increased actual fertilizer usage,[19] it is striking that a 17 percent reduction in the price of fertilizer immediately after harvest, which still required a visit to the shop, potentially led to almost as large an increase in fertilizer purchases as a 50 percent reduction in the cost of fertilizer with free delivery at the time fertilizer needs to be used. Since we did not monitor farmers to see who actually used fertilizer, we cannot know how much of this was offset in reduced purchases from other sources. We also cannot rule out the possibility of some resale of fertilizer, but we believe it is unlikely there was much resale since prices on the resale market typically involve substantial discounts, and the total discount farmers received for 5 kilograms of fertilizer was only Ksh 30 (about US $0.50). This makes a strategy of purchase for resale, therefore, seem unattractive. Overall, this pilot version of the time-limited subsidy is thus encouraging that a time-limited small discount program on fertilizer may be an effective, easy to scale up, policy to encourage fertilizer use without distorting decision making and inducing excessive use of fertilizer.

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[19] In fact, purchases through the program were similar to control group adoption in the programs reported earlier in the paper, though there may have been seasonal differences between those years and the coupon program.

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Table 1. SAFI & Subsidy Programs

Panel A. SAFI for Season 1	SAFI (1)	Comparison (2)	Difference (3)
SAFI Season 1			
Income (in 1,000 Kenyan shillings)	2.10	2.86	-0.77
	(5.51)	(6.70)	(0.52)
Years Education Household Head	6.62	7.20	-0.58
	(3.96)	(4.13)	(0.321)*
Household had Used Fertilizer Prior to Season 1	0.43	0.43	0.01
	(0.50)	(0.50)	(0.04)
Home has Mud Walls	0.91	0.87	0.04
	(0.29)	(0.33)	(0.03)
Home has Mud Floor	0.90	0.85	0.05
	(0.31)	(0.36)	(0.027)*
Home has Thatch Roof	0.56	0.52	0.05
	(0.50)	(0.50)	(0.04)
Observations	211	713	924
Post Treatment Behavior			
Household bought fertilizer through program	0.31	-	-
	(0.46)	-	-
Observations	242	-	
Adoption in Season of Program	0.45	0.34	0.11
	(0.50)	(0.47)	(0.038)***
Observations	204	673	

Note: In each Panel, means and standard deviations for each variable are presented, along with differences (and standard errors of the differences) between each treatment group and the comparison group. The comparison group in Panel A consists of those not sampled for both SAFI, even if they had been sampled for other treatments (see text and Table 2).
Exchange rate was roughly 70 Kenyan shillings to US $1 during the study period.
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 1 (continued). SAFI & Subsidy Programs

	SAFI	SAFI with Timing Choice	Subsidy at Top Dressing	Full Price at Top Dressing	Comparison
	(1)	(2)	(3)	(4)	(5)
SAFI Season 2					
Means					
Baseline Characteristics					
Income (in 1,000 Kenyan shillings)	2.84	2.86	2.29	2.81	2.40
	(7.53)	(7.36)	(4.01)	(6.68)	(4.47)
Years Education Household Head	6.99	6.84	7.13	6.99	7.58
	(3.98)	(4.12)	(4.13)	(4.02)	(4.30)
Household had Used Fertilizer Prior	0.42	0.41	0.38	0.44	0.51
to Season 1	(0.49)	(0.49)	(0.49)	(0.50)	(0.50)
Home has Mud Walls	0.88	0.89	0.86	0.91	0.87
	(0.33)	(0.32)	(0.35)	(0.29)	(0.34)
Home has Mud Floor	0.83	0.88	0.85	0.89	0.86
	(0.38)	(0.33)	(0.36)	(0.32)	(0.35)
Home has Thatch Roof	0.53	0.53	0.49	0.55	0.53
	(0.50)	(0.50)	(0.50)	(0.50)	(0.50)
Observations	228	235	160	160	141
Post Treatment Behavior					
HH bought fertilizer through program	0.39	0.41	0.46	0.20	-
	(0.49)	(0.49)	(0.50)	(0.40)	-
Observations	208	207	145	143	-
Adoption in Season of Program	0.38	0.47	0.41	0.33	0.28
	(0.49)	(0.50)	(0.49)	(0.47)	(0.45)
Observations	179	208	133	135	102
Differences Between Treatment and Comparison					
Baseline Characteristics					
Income	0.440	0.456	-0.110	0.402	-
	(0.727)	(0.714)	(0.514)	(0.692)	-
Years Education Household Head	-0.595	-0.740	-0.456	-0.588	-
	(0.440)	(0.446)*	(0.487)	(0.479)	-
Household had Used Fertilizer Prior	-0.094	-0.100	-0.129	-0.073	-
to Season 1	(0.053)*	(0.053)*	(0.057)**	(0.058)	-
Home has Mud Walls	0.005	0.013	-0.012	0.034	
	(0.035)	(0.035)	(0.040)	(0.036)	
Home has Mud Floor	-0.034	0.018	-0.010	0.029	
	(0.040)	(0.036)	(0.041)	(0.038)	
Home has Thatch Roof	0.006	0.003	-0.031	0.025	
	(0.054)	(0.053)	(0.058)	(0.058)	
Observations	228	235	160	160	141
Post Treatment Behavior					
Adoption in Season of Program	0.105	0.197	0.139	0.051	-
	(0.059)*	(0.059)***	(0.063)**	(0.060)	-
Observations	179	208	133	135	-

Note: In each Panel, means and standard deviations for each variable are presented, along with differences (and standard errors of the differences) between each treatment group and the comparison group. The comparison group consists of those not sampled for both SAFI, even if they had been sampled for other treatments (see text and Table 2).
The number of observations is the number of farmers in each group with non-missing adoption data in the season of the program.
Exchange rate was roughly 70 Kenyan shillings to US $1 during the study period.
* significant at 10%; ** significant at 5%; *** significant at 1%

Table 2. Adoption for Parents Sampled for SAFI & Subsidy Programs

	Used Fertilizer Season 1		Used Fertilizer Season 2		Used Fertilizer Season 3	
	(1)	(2)	(3)	(4)	(5)	(6)
SAFI Season 1	0.114	0.143	0.007	0.007	0.006	0.01
	(0.035)***	(0.038)***	(0.041)	(0.044)	(0.037)	(0.041)
Starter Kit Farmer	0.059	0.080	0.024	0.005	-0.009	-0.027
	(0.042)	(0.046)*	(0.047)	(0.051)	(0.043)	(0.048)
Starter Kit Farmer * Demonstration Plot School	-0.026	-0.061	0.024	-0.005	0.004	-0.031
	(0.060)	(0.066)	(0.068)	(0.075)	(0.063)	(0.070)
Demonstration Plot School	0.006	0.441	0.362	0.464	0.362	0.437
	(0.314)	(0.435)	(0.460)	(0.463)	(0.335)	(0.465)
Household had Used Fertilizer Prior to Season 1	0.369	0.315	0.319	0.284	0.281	0.251
	(0.031)***	(0.035)***	(0.035)***	(0.040)***	(0.033)***	(0.037)***
Male		0.012		0.014		0.026
		(0.033)		(0.037)		(0.034)
Home has mud walls		-0.193		-0.183		-0.021
		(0.081)**		(0.091)**		(0.085)
Education primary respondent		0.004		-0.004		0.015
		(0.004)		(0.005)		(0.005)***
Income in past month (in 1,000 Kenyan shillings)		0.004		0.006		0.002
		(0.003)		(0.003)**		(0.003)
Observations	876	716	756	626	902	734

	Used Fertilizer Season 1		Used Fertilizer Season 2		Used Fertilizer Season 3	
Panel B. 2004 Season 2 Treatments	(1)	(2)	(3)	(4)	(5)	(6)
SAFI Season 2	-0.009	0.042	0.165	0.181	-0.024	-0.005
	(0.053)	(0.057)	(0.061)***	(0.066)***	(0.056)	(0.061)
SAFI Season 2 with Choice on Date of Return	-0.014	0.03	0.207	0.216	-0.027	0.003
	(0.048)	(0.053)	(0.055)***	(0.060)***	(0.050)	(0.056)
Half Price Subsidy Visit at Top Dressing	-0.035	-0.039	0.142	0.127	0.023	0.041
	(0.052)	(0.057)	(0.059)**	(0.065)*	(0.054)	(0.061)
Full Price Visit at Top Dressing	-0.065	-0.034	0.096	0.104	-0.053	-0.031
	(0.052)	(0.058)	(0.059)	(0.066)	(0.054)	(0.061)
Bought Maize	-0.002	-0.011	-0.042	-0.079	0.002	-0.014
	(0.043)	(0.048)	(0.049)	(0.054)	(0.046)	(0.050)
Bought Maize * SAFI Season 2	-0.048	-0.073	-0.085	-0.057	0.005	-0.011
	(0.075)	(0.082)	(0.087)	(0.096)	(0.080)	(0.087)
Household had Used Fertilizer Prior to Season 1	0.369	0.316	0.325	0.283	0.278	0.248
	(0.031)***	(0.035)***	(0.035)***	(0.040)***	(0.033)***	(0.037)***
Male		0.01		0.014		0.028
		(0.033)		(0.037)		(0.035)
Home has mud walls		-0.197		-0.197		-0.017
		(0.081)**		(0.091)**		-0.086
Education primary respondent		0.004		-0.003		0.015
		(0.004)		(0.005)		(0.005)***
Income in past month (in 1,000 Kenyan shillings)		0.004		0.006		0.003
		(0.003)		(0.003)**		(0.003)
Mean Usage in Comparison Group	0.247	0.228	0.297	0.300	0.392	0.397
Observations	876	716	756	626	902	734

Note: Dependent variable is an indicator equal to 1 if the farmer adopted planting or top dressing fertilizer in the given season. All regressions control for school, and whether the farmer was a parent of a Standard 5 or 6 child (see text). Panel B also include controls for the Season 1 Treatments listed in Panel A.
The comparison group means listed in the bottom of the table are for individuals that did not participate in either SAFI, were not offered fertilizer at any price, and did not participate in the starter kit program. This accounts for the difference in mean usage between this Table and Table 1.
There are fewer observations than in Table 1 because of missing values for previous usage. For all programs listed above, respondents were allowed to buy either DAP (for planting) or CAN (for top dressing) fertilizer.
Exchange rate was roughly 70 Kenyan shillings to US $1 during the study period.
Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%

Table 3. Acceptance of Various Commitment Savings Pilot Products (SAFI Program)

	---------------- All Pilots ----------------				Versions Offered in Same Season			
	Initially Accepted	*Initially Accepted*	*Bought Fertilizer*	*Bought Fertilizer*	*Initially Accepted*	*Initially Accepted*	*Bought Fertilizer*	*Bought Fertilizer*
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
SAFI Variants								
option 1: take-it-or-leave-it	0.637	0.591	0.637	0.651	0.471	0.580	0.471	0.644
	(0.048)***	(0.079)***	(0.044)***	(0.074)***	(0.125)***	(0.210)***	(0.097)***	(0.163)***
option 2: return in a few days	0.700	0.662	0.300	0.311	0.471	0.514	0.294	0.395
to collect money	(0.068)***	(0.086)***	(0.063)***	(0.080)***	(0.125)***	(0.165)***	(0.097)***	(0.128)***
option 3: return in a few months	0.606	0.563	0.169	0.164	0.500	0.555	0.000	0.090
to collect money	(0.057)***	(0.069)***	(0.053)***	(0.064)**	(0.121)***	(0.150)***	(0.094)	(0.117)
Other Controls								
Household had Used Fertilizer		0.144		0.114		0.244		0.080
Prior to the Program		(0.068)**		(0.064)*		(0.175)		(0.136)
Years of Education		-0.002		-0.008		-0.024		-0.026
Household Head		(0.009)		(0.008)		(0.023)		(0.018)
School Controls	No	Yes	No	Yes	No	Yes	No	Yes
F-test, option 1 = option 2 (p-value)	0.451	0.397	0.001***	0.001***	1.000	0.725	0.202	0.095*
F-test, option 1 = option 3 (p-value)	0.671	0.716	0.001***	0.001***	0.866	0.895	0.001***	0.001***
F-test, option 2 = option 3 (p-value)	0.290	0.269	0.114	0.079*	0.866	0.816	0.034**	0.03**
Observations	223	222	223	222	52	52	52	52

Notes: Figures are from the pilot SAFI programs, which were conducted mostly among farmers that participated in demonstration plot trials. Averages are pooled across a number of different seasons. The dependent variable is take-up rate (not actual usage of fertilizer). Means are reported, along with p-values for F-tests for pairwise testing of take-up rates.
Standard errors in parantheses. * significant at 10%; ** significant at 5%; *** significant at 1%

Table 4. Reminder Intervention

	Bought Top Dressing Fertilizer			Planned to Buy Top Dressing Fertilizer			Bought or Planned to Buy Top Dressing Fertilizer		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
SAFI Season 2	-0.035	-0.026	-0.088	0.053	0.036	0.038	0.019	0.015	0.000
	(0.055)	(0.056)	(0.072)	(0.075)	(0.077)	(0.094)	(0.072)	(0.074)	(0.093)
Household had Used Fertilizer		0.069	0.057		0.105	0.149		0.141	0.142
Prior to Season 1		-0.058	-0.074		-0.081	-0.096		(0.077)*	-0.096
Male			0.036			-0.132			-0.117
			(0.069)			(0.090)			(0.090)
Home has mud walls			-0.137			-0.101			-0.197
			(0.154)			(0.206)			(0.198)
Education primary respondent			0.008			0.003			0.011
			(0.010)			(0.013)			(0.013)
Income in past month			-0.001			0.002			0.000
(in 1,000 Kenyan shillings)			(0.005)			(0.006)			(0.006)
Mean of Dependent Variable among Comparison Farmers	0.224	0.206	0.240	0.33	0.345	0.295	0.514	0.510	0.493
Observations	195	188	141	172	166	121	193	186	139

Notes: See text for description of program. The dependent variable in columns 1-3 is an indicator variable equal to 1 if the farmer had already bought top dressing fertilizer, the dependent variable in columns 4-6 is an indicator variable equal to 1 if the farmer planned to buy top dressing fertilizer that season, and the dependent variable in columns 7-9 is an indicator variable equal to 1 if the farmer had already bought or planned to buy fertilizer in that season. In addition to variables listed, all regressions control for all demonstration plot, SAFI, and subsidy treatments.
Standard errors in parentheses. * significant at 10%; ** significant at 5%; *** significant at 1%

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Table A1. Examining Differential Response Rates

	Completed 2004 Background Questionnaire	Completed 2005 Adoption Questionnaire	Completed 2005 Adoption Questionnaire
	(1)	(2)	(3)
Starter Kit Farmer	0.009	0.047	0.047
	(0.039)	(0.038)	(0.038)
Demonstration Plot School	-0.261	0.245	0.245
	(0.319)	(0.316)	(0.316)
Starter Kit Farmer * Demonstration Plot School	0.054	0.035	0.035
	(0.050)	(0.050)	(0.050)
SAFI Season 1	0.043	0.050	0.050
	(0.043)	(0.042)	(0.042)
SAFI Season 2	0.003	0.002	0.002
	(0.054)	(0.054)	(0.054)
SAFI Season 2 with Choice	0.041	0.037	0.037
	(0.054)	(0.053)	(0.053)
Subsidy Season 2	0.082	0.083	0.083
	(0.059)	(0.059)	(0.059)
Full Price Visit Season 2	0.109	0.088	0.088
	(0.060)*	(0.059)	(0.059)
ICS Bought Maize Season 2	0.026	0.000	0.000
	(0.034)	(0.033)	(0.033)
Sample	Whole Sample	Whole Sample	Only those that completed Background
Mean of Dependent Variable	0.751	0.754	0.906
Observations	1230	1230	1230

Notes: * significant at 10%; ** significant at 5%; *** significant at 1%
Regressions control for school and for interactions between the demonstration plot and the various treatments.
Overall, 90.6% of respondents that completed the 2004 questionnaire also completed the 2005 questionnaire.

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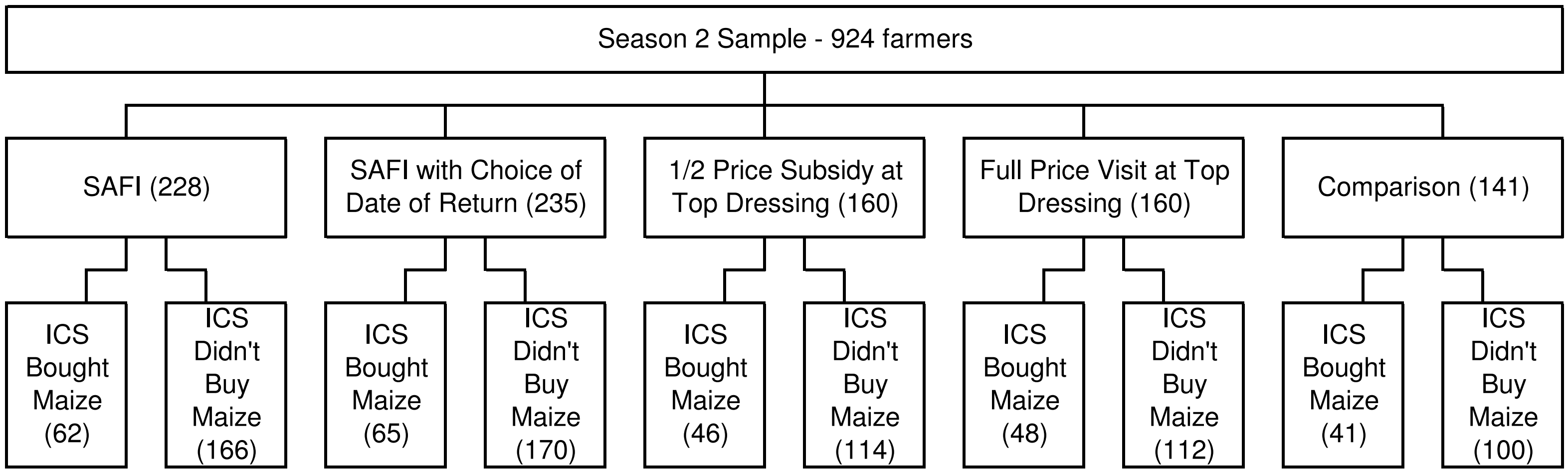
Table A2. Verifying Randomization for Pilot SAFI Programs

	Household had Ever Used Fertilizer Before (1)	Years Education (2)	Home has Mud Walls (3)	Home has Mud Floors (4)	Home has Thatch Roof (5)	Income in Month Prior to Survey^ (6)	Number of Children (7)	Acres of Land Owned (8)
SAFI Variants								
option 1: take-it-or-leave-it	0.455	7.223	0.780	0.810	0.420	1.829	7.298	3.990
	(0.500)	(3.419)	(0.416)	(0.394)	(0.496)	(2.715)	(2.758)	(3.097)
option 2: return in a few days	0.340	6.040	0.780	0.840	0.460	1.672	7.000	4.391
to collect money	(0.479)	(4.130)	(0.418)	(0.370)	(0.503)	(2.275)	(2.678)	(3.508)
option 3: return in a few months	0.352	4.254	0.833	0.722	0.556	2.359	9.471	3.844
to collect money	(0.481)	(4.013)	(0.383)	(0.461)	(0.511)	(5.814)	(3.281)	(2.663)
F-test, option 1 = option 2 (p-value)	0.470	0.162	0.901	0.565	0.452	0.665	0.834	0.355
F-test, option 1 = option 3 (p-value)	0.847	0.077*	0.350	0.965	0.630	0.332	0.208	0.645
F-test, option 2 = option 3 (p-value)	0.732	0.475	0.400	0.681	0.995	0.220	0.166	0.905
Observations	222	222	168	168	168	169	158	163

Notes: Figures are from the pilot SAFI programs, which were conducted mostly among farmers that participated in demonstration plot trials.
Means are reported, with standard deviations in parentheses.
The bottom of the table reports p-values of F-tests for pairwise testing of means across SAFI options.
^Income is measured in 1,000 Kenyan shillings. Exchange rate was roughly 70 shillings to $1 US during the sample period.
* significant at 10%; ** significant at 5%; *** significant at 1%



Finally, within each cell, farmers were randomly selected for a "reminder" visit that occurred just before top dressing.
In total, 88 farmers were sampled for the reminder, and 107 served as reminder comparison farmers

Appendix Figure 1. Experimental Design for School-Based Starter Kit Program for 2004 Short Rains

Notes: Number of farmers include all farmers that were traced for the baseline questionnaire (prior to the Season 1 treatments). Sampling for all Season 2 treatments is stratified by Season 1 treatments.