Risk and sustainable crop intensification

Bjorn Van Campenhout

Invited paper presented at the 5th International Conference of the African Association of Agricultural Economists, September 23-26, 2016, Addis Ababa, Ethiopia

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The Case of Small-holder Rice and Potato Farmers in Uganda

Bjorn Van Campenhout, Research Fellow, International Food Policy Research Institute (IFPRI)

Abstract

To feed a growing and increasingly urbanized population, Uganda needs to increase crop production without further exhausting available resources. Therefore, smallholders farmers are encouraged to adopt sustainable crop intensification methods such as inorganic fertilizer or hybrid seeds. However, these farmers perceive these new technologies as risky, hence adoption will depend on how well they can manage this additional risk. This article documents patterns observed in socio-economic data that suggest risk is an important barrier to sustainable crop intensification practices among Ugandan small-holder rice and potato farmers.

Introduction

Like many low income countries, especially in sub-Saharan Africa, Uganda is an overwhelmingly agrarian society, with 72 percent of the working population engaged in agriculture. Much of this agriculture takes the form of subsistence farming, where farmers produce food crops for auto-consumption using rudimentary technologies and few inputs sourced from the market. The expenses for the few goods and services that households buy from the market, such as soap and health care, are met by selling small amounts of the crop, usually immediately after harvest or as the need arises at low prices. This autarkic way of living, shying away from markets with its modern inputs and technologies, appears to be sufficient to sustain livelihoods in Uganda in normal circumstances, due to favorable soils and climatic conditions. But it also keeps well-being low, often trapping households into chronic poverty, and vulnerable to a myriad of shocks, such as conflicts, price risk, abrupt policy changes, and extreme weather events.

High population growth and rapid urbanization means yields need to increase without further exhausting available resources. Fertility rates in Uganda remain amongst the highest in the world, putting pressure on per capita land availability in an area that is characterized by an already high population density. This results in land fragmentation, with plots becoming too small to sustain households, further fueling the rural exodus of people entering their most productive years. There is thus an urgent need to grow more on smaller plots. At the same time, a new international food price environment provides an opportunity for small-holder farmers to break out of subsistence, especially in the longer run (Van Campenhout et al., 2013). Yields need to increase to allow smallholders to benefit from these higher prices, as farmers need to generate a marketable surplus that they can sell on the market (Mather et al., 2013).

The use of modern inputs, such as synthetic nitrogen fertilizers and high yielding cultivars, together with access to appropriate technology, is often touted as the best way to increase crop yields. This is inspired on the experience in Latin America and Asia, where the green revolution was able to increase wheat, rice and maize yields dramatically in a short time. These days, there many initiatives in developing countries (such as the Alliance for a Green Revolution in Africa (AGRA)) that aim to increase the use of modern inputs. Also in Uganda, the private sector and non-government actors, though provision of inputs, as well as government and development partners, through the creation of an enabling environment, view sustainable crop intensification as an important development strategy.

It is often argued that the use of such modern inputs exposes poor households to even more risk. Indeed, farming is already a risky business. There are the obvious weather risks inherent to rain-fed agriculture, and climate change and global warming is expected to increase the occurrence of extreme events such as droughts and floods. In addition, farmers are often confronted with policy shocks. For example, Dercon (2002) finds that in Ethiopia between 1994 and 1997, the second most mentioned shocks were policy related, such as sudden changes in taxation and migration bans. If farmers interact with the market, prices also become a source of uncertainty and poorly integrated markets and seasonality cause substantial price volatility. In the humid tropics, there are also many health risks, such as malaria affecting human capital or nagana (transmitted by tsetse flies) affecting livestock assets (Fink et al., 2015).

Small-holder farmers use a host of risk management and risk coping strategies to deal with this risk. The most effective risk management strategy would be to take insurance, but this is rarely an option for small-holder farmers. A strategy that is often observed among poor farmers is diversification. Instead of specializing in a single crop, farmers will cultivate different crops, such that if one crop fails, the farmer does not loose everything. The farmer will choose a crop mix that varies along certain attributes (such as time of maturity, resilience to drought, etc.) to reduce covariance in output. Farmers may also have ways to reduce the consequences of a shock ex-post, such as relying on kinship networks.

Perceived risk associated with the use of modern inputs adds to this risk, and some argue that risk avoidance and inability to take on risk is key to understanding lack of sustained intensification

(Eswaran et al., 1990; Dercon, 1996; Dercon et al., 2011; Karlan et al., 2014). Especially poor farmers may have limited options to insure against downside consumption risk and stick with low-risk low-return crops and technology. Such households are more likely to be poor in the future and as such are locked into a poverty trap. These households may refrain from taking even the slightest risk, as the consequences may hit them especially hard. This also explains why simply making improved inputs and technologies available to poor farmers does not also automatically mean they will embrace them. Recent research finds that insurance influences production decisions in India and Ghana, in line with this hypothesis (Cole et al., 2013b; Karlan et al., 2014).

In this paper, we explore the relevance of risk considerations for sustainable crop intensification in a case study of potato and rice growing small-holder farmers in Uganda. We start by providing the context and explaining the data we have collected for this study and look at the potential for intensification, as well as the risk associated with it. We then give a brief overview of what risk management strategies smallholders typically use. Next, we look at intensification patterns and how they relate to different risk management strategies we identify in the data. We then bring everything together, run some more formal tests and estimate probit models. A final section concludes and draws some lessons for policy making.

Rice and potato growing in Uganda - the data

Both the rice and potato sectors are quickly gaining importance in Uganda. According to the Uganda Census of Agriculture, rice production increased substantially, from 52,000 tons in the 1999/00 agricultural season to almost 200,000 tons in 2008/09. In 2008/09, about 75,000 hectares were under rice cultivation, resulting in rice yields of about 2.55 tons per hectare, although there are significant regional differences. Most of the rice is produced in the Eastern region, which also has the highest yields, followed by the Northern region. Potato production increased nationally from 208,000 tons in 1999/00 to 382,000 tons in 2008/09. Kisoro was clearly the leading district, accounting for 36 percent of total production.

Between June and August 2014, we collected detailed socio-economic data from about 880 small-holder farmers in Uganda. Our study population consisted of rice farmers around lake Kyota in Eastern Uganda and potato farmers in the South Western part of Uganda. For the rice survey, we sampled from 3 districts (Bugiri, Butaleja and Tororo). For the potato survey, we also sampled from three districts (Kabale, Kanungu and Kisoro). Sampling of households was done with the assistance of the Uganda Bureau of Statistics (UBOS). We ended up with a sample of 489 potato farmers and 398 rice farmers.

Table 1: percentages of households using modern inputs

	Fertilizer	Pesticides
potatoes	34.6	66.7
rice	14.5	17.9
both	25.6	47.5

Table 1 demonstrates moderate use of modern inputs in Uganda. We find that about one quarter of households are using some kind of fertilizer on at least one of their rice or potato plots. In fact, if we disaggregate by crop, we find it are especially the potato farmers that are using fertilizer. Almost half of the households report to be using pesticides, herbicides and/or fungicides[1]. Potato farmers use relatively more of these inputs than rice farmers. Actual fertilizer application (in kilograms per hectare) is low, especially for rice.

Is there Potential for Intensification?

Figure 1, showing yields of both potatoes (left) and rice (right) in our sample, suggests substantial room for crop intensification. Defining yields as metric tons per hectare (MT/ha), we find that median yield is 3.2 MT/ha for potatoes and 1.7 MT/ha for rice. The distribution of potato yields is skewed to the right, and mean yields are as high as 5.2 MT/ha. The distribution of yields is less skewed for rice, where the mean is about 2 MT/ha. Maximum yields in our sample are 11.1 MT/ha for potatoes and 3.6 MT/ha[2]. Potential yields are yields that have been recorded under optimal conditions in experiments conducted at research stations. Potential yield for potato, at about 21.6 tons per acre was taken from Fermont et al. (2011) (Table 5). Potential yield for rice was taken to be the yield of Nerica 4, which is about 5 tons according to the Nerica compendium[3].

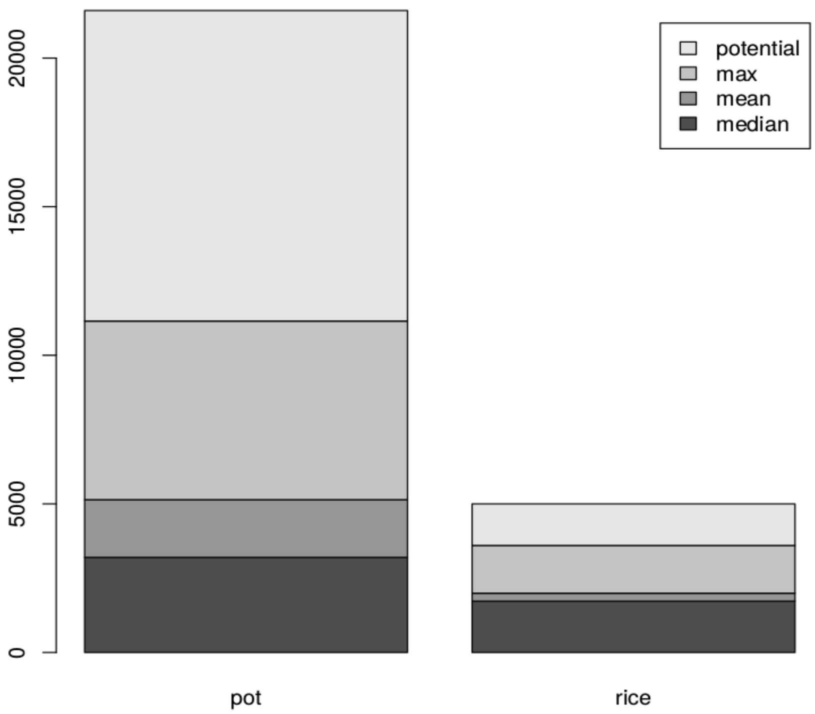
Especially for potatoes, the gap between median or average yields on the one hand, and potential yields on the other hand are large. Median yields are only about 15 percent of potential yields. This gap is smaller for rice. Maximum yields are for both rice and potatoes about twice the average yields. This suggests that, especially for potato growing, sustainable crop intensification through the use of fertilizers, pesticides, improved cultivars and modern technologies can boost yields substantially.

Figure 1: rice and potato yields

1 Throughout the paper, we have aggregated pesticides, herbicides and fungicides into one category, which we will simply refer to as pesticides.

2 The maximum is defined as the ninth decile.

3 http://www.africarice.org/publications/nerica-comp/Nerica%20Compedium.pdf



We also find that, in our sample, intensification seems to work[4]. For instance, we see clear differences in median yields if we compare households that report not to engage in any form of intensification with households who do. The left bar plot in Figure 2 shows that potato farmers that do not use fertilizer or pesticides have yields of about 1.5 MT/ha[5]. These yields double to almost 3 MT/ha for potato growers that report to be using fertilizer. The returns to pesticides appear to be even higher. The subgroup of farmers that report using pesticides get median yields of 4 MT/ha. For those who use both fertilizer and pesticides, yields are more than 3 times the yields of a farmer that does not intensify.

For rice, we also find clear positive correlations between the use of fertilizer and pesticides and yields, although the differences are somewhat less spectacular than for potatoes. We find that fertilizer and pesticides have virtually equal effects, increasing yields by about 65 percent. Using

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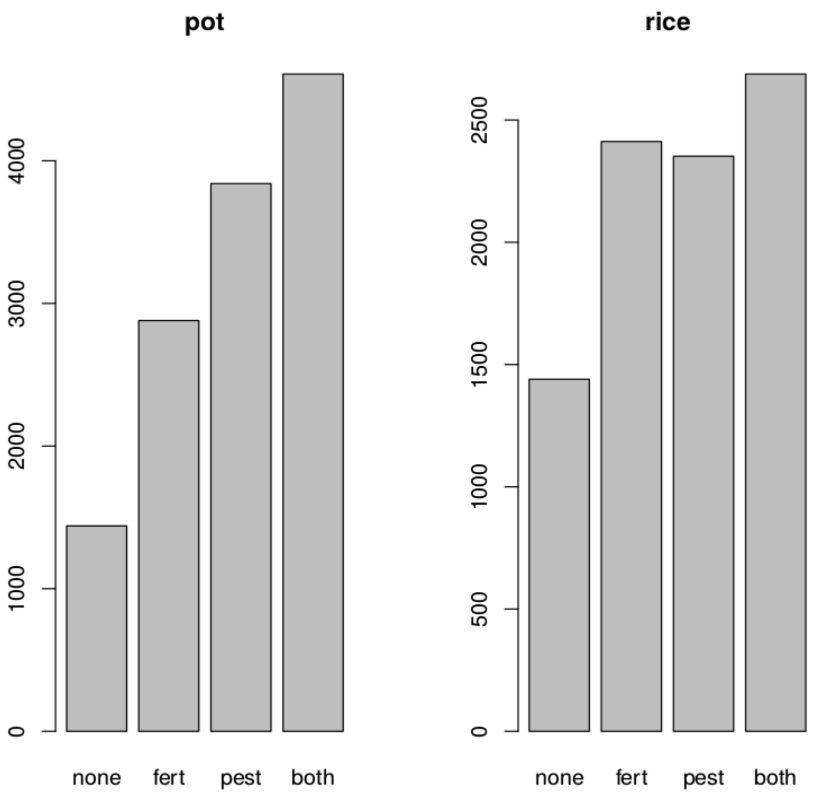
4 The usual disclaimer that correlation does not implies causation applies here, hence the qualification that intensification seems to work as opposed to the assertion that intensification works. As we are using observational data (as opposed to data obtained from an experiment), our results are likely to be affected by endogeneity. In other words, some of these correlations may simply reflect "joint determination" of variables of interest by another variable or two way causality.

5 We use fertilizer and pesticides as indicators of intensification for most of our study. An additional form of intensification often found in the literature is improved seed varieties. However, it is often hard to define and trace what seeds are assumed to be improved and which are traditional. For instance, in our data, most farmers used improved seeds, but it was often not clear how often those seeds had been recycled.

both fertilizer and pesticides increased median rice yield by about 86 percent. While it is likely that these numbers are an overestimation of the true causal effect of fertilizer and pesticide use on yields, the sheer size of the differences suggests intensification raises yields in both rice and especially potato growing. We also find that intensification is profitable. Partial profit, defined as the value of the harvest minus the cost of fertilizer and pesticides, increases about 70 percent with the use of modern inputs.

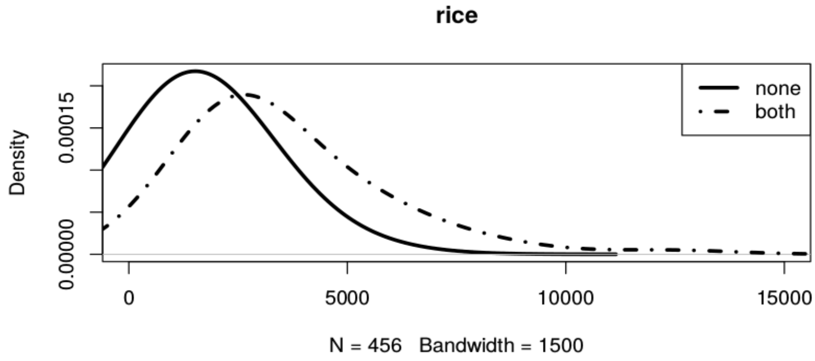
Figure 2: median yields and intensification

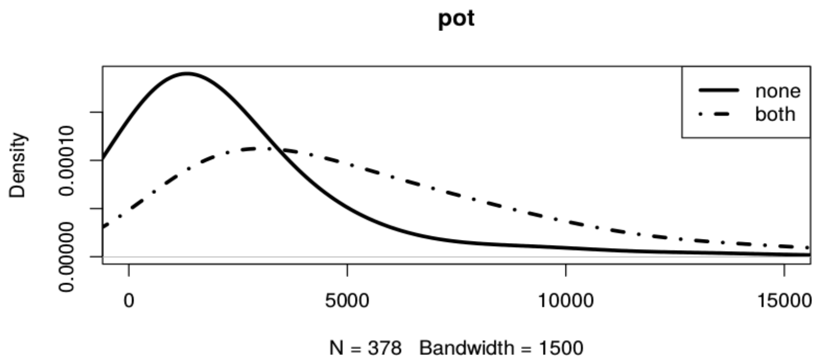


However, adoption of new technologies may be seen as risky, especially early in the adoption process when proper use and average yields are not well understood. In other words, while the use of a certain input may increase the chance that one ends up with a higher quantity produced, it may at the same time increase the chance that one ends up with a lower outcome. In fact, the use of modern inputs is likely to affect the entire distribution, not just the mean and standard deviation. As such, it is important to look at the entire probability distribution associated with agricultural productivity outcomes. Kernel density estimation is a convenient way to compare probability density functions.

In general, the use of fertilizers and pesticides among Ugandan potato and rice farmers shifts the yields distribution to the right, thereby slightly increasing the variance. This can be seen in Figure 3. The figure shows kernel density estimates for rice in the top panel and potatoes in the bottom panel. We have plotted two density curves. The solid line represents the distribution of yields for the subset of farmers that report not using any fertilizers or pesticides. The dash and dot line represents the distribution of yields of the subset of farmers that report using both fertilizers and pesticides. We see that probability is highest around 2 MT/ha for rice growers and potato growers that do not use modern inputs. For rice, probability becomes highest at around 2.6 MT/ha, while this is about 3 MT/ha for potato. Variance seems to increase in both cases, but most for potatoes.

Figure 3: Kernel density estimates for yields





Downside yield risk does not seem to increase with intensification. That is, at the lower end of the distribution (below say 2 MT/ha), we find that the probability density function for the subset of farmers that use fertilizers and pesticides is always below the probability density function of farmers that do not use modern inputs. In other words, for farmers that use modern inputs, the chance of getting a low outcome (such as zero MT/ha) is always lower than that of a farmer that does not use inputs. In statistical terms, the distribution of the subset of farmers using both fertilizer and pesticides first order dominates the distribution of the subset of farmers that are not using any inputs. Downside profit risk also does not seem to increase with intensification.

Risk Management and Risk Coping

Farmers are faced with a myriad of risks, which they try to insure against using a host of risk management and risk coping strategies and mechanisms. It has been argued that the ability to take on additional risk related to crop intensification will also be influenced by ex-ante risk management strategies already in place and to a lesser extent on ex-post coping mechanisms employed by the household (eg. Dercon et al., 2011). To see if this also holds for our case study, we check if intensifiers are also on average better insured. Thus, if fertilizer and/or pesticide use is found more frequently among households that have proper insurance in place, this suggests that crop intensification is perceived as a risky activity that needs to be properly hedged. Or, if we find that households with limited risk management strategies and risk coping options are also the ones not using fertilizer and pesticides, this may indicate that households view these technologies as too risky for them given their limited insurance options.

Figure 4: risk management and coping strategies

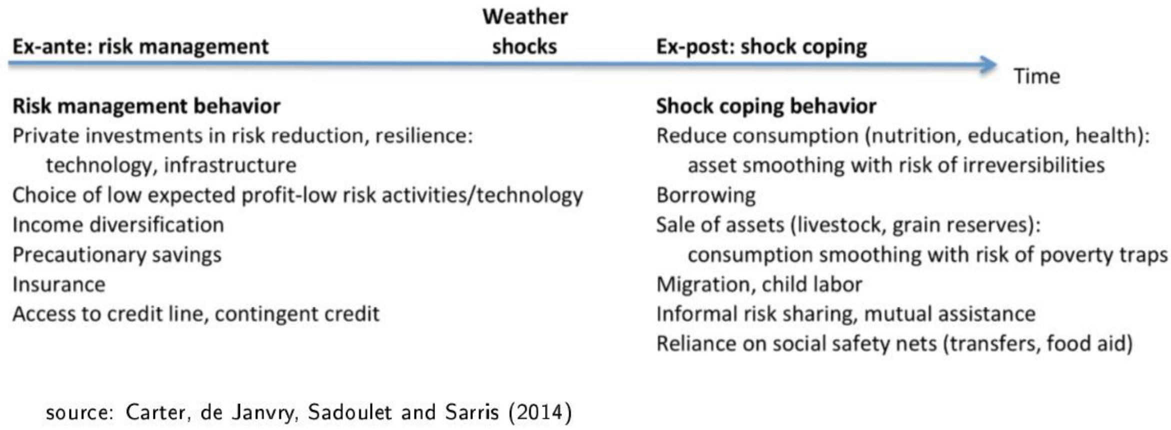


Figure 4, taken from Carter et al. (2014), lists the most important risk-management and risk coping strategies that farm households typically use. Ex-ante risk-management behavior includes private investment in risk reducing technology and infrastructure. For instance, households may decide to invest in a proper storage facility to reduce post harvest loss risk, or they may invest in communications technology to reduce price risk when entering the market. Income skewing, where households choose to engage in activities that have low risk (but are typically also lower in return (Rosenzweig et al., 1993b; Mosley et al., 2005)), is another way in which poor people who do not have access to formal insurance try to cope with uncertainty. In agricultural settings, this skewing is also often reflected in the crop mix, where people allocate disproportionate areas to food security crops such as sweet potatoes and millet. These crops are resistant to drought, but also fetch lower prices on the market than, say, maize or rice. Related to income skewing is income diversification, where income from different sources is preferred to specialization. If the income from farming is below expectations, then other sources of income, such as beer brewing, may be able to fill the gap.

Precautionary savings during years of above average income is also an important way to deal with downside risk in the future. However, in agricultural settings where formal savings institutions are absent, savings are often stored in assets such as livestock. In times of stress, it is often found that households start selling these assets at the same time, leading to a collapse of livestock prices. In addition, in the case of livestock, the shock is likely to affect the quality of the assets, further reducing its price. The negative correlation between asset prices and food prices in times of stress quickly makes precautionary savings less effective as an insurance strategy (Dercon, 2002).

Obviously, insurance would be the most appropriate and effective way to insure against shocks.

However, in the context of high transaction costs, adverse selection and principal agent problems have resulted in few insurance instruments being promoted in Africa. Index-based insurance, where sums are paid out on the basis of easily observable indicators, have been touted as the most appropriate insurance contract form in agriculture in rural areas in lower income countries. However, while some have found index based insurance to be a useful complement to other risk mitigating strategies (Dercon et al., 2014; Karlan et al., 2014), it is not a panacea. Index insurance uptake generally remains much lower than initially expected and more research is needed to find out why this is so (Cole et al., 2013a). Access to credit is often considered a close substitute to insurance, and indeed suffers from much of the same principal-agent problems than insurance (Eswaran et al., 1989; Udry, 1990).

On the right hand side, Figure 4 also shows various coping strategies that household typically use to cope with the consequences once a risk has materialized. For instance, household may reduce consumption as a response to a shock, or take children out of school to engage in child labor, which is likely to result in long run consequences. Alternatively, households may be able to cope with a shock by sharing the losses with others within the village (in the case of idiosyncratic shock) or among relatives in other parts of the country (in the case of common shocks). But informal risk sharing can also be used as an ex-ante risk management strategy. For example, share-cropping is often used as a way to share risk between the farmer and equity holders. Also, cultivating land that has been rented in instead of owning land can be regarded as a strategy to share risk in the medium run. Other forms of coping are borrowing or selling of assets.

We will mainly focus on ex-ante risk management strategies that households use to explore the relationship between risk and intensification, and much less on coping mechanisms. This is because the decision to intensify farm investment is made before the risk has been materialized. At that point, the decision maker will consider all his options. As such, what matters at that point in time is not happens ex-post, but what the decision maker ex-ante expects what will be possible in terms of ex-post coping. For instance, it is irrelevant to the decision to invest whether the farmer borrows ex-post. What is relevant is whether the farmer thinks at the time of the decision to intensify that he or she will be able to borrow when things go wrong. As such, what matters for the decision to invest or not is access to credit.

Risk Management and Intensification in Uganda

We first look at private investments in risk reducing technologies. We then explore if there is a relation between crop portfolio diversification and intensification behavior. We also look at precautionary savings and access to credit. We then turn to some more formal statistical tests and finally bring all these risk management strategies together and estimate a simple logit models.

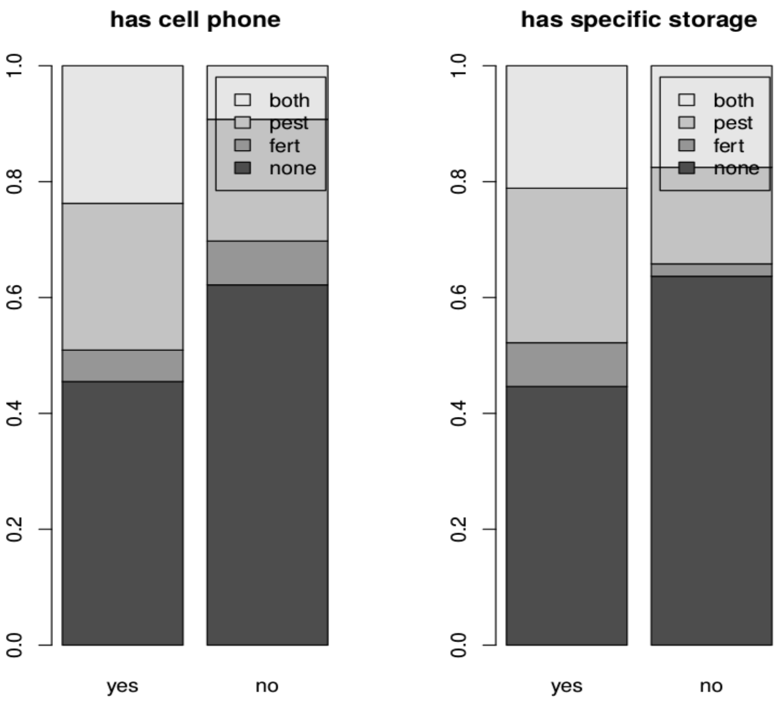
Private Investment in Risk Reducing Technologies

One source of uncertainty for farmers is price risk. Price risk has both a temporal and a spatial component. The temporal component refers to the fact that one can not predict the future. In general, temporal price risk can be reduced through futures contracts or other means of agricultural commodity price hedging. Spatial price risk refers to uncertainty about the price of a good in a different market in the same commodity at a particular point in time. Spatial price risk, resulting from poorly integrated markets and high transaction costs, can be mitigated by reducing search costs. Reducing search costs means that prices over a larger area can be compared for the same effort. This information can then be used by the farmer to decide in which market to sell in or to strengthen the bargaining position vis-a-vis middlemen.

Recent research has looked at the potential of Information and Communication Technologies (ICTs), especially in the form of mobile phones, to reduce search costs. The seminal study of Jensen (2007) shows how fishermen in India use mobile phones to search for the market with the highest demand and lowest supply, thereby significantly reducing aggregate price volatility. The evidence for agriculture is less clear-cut. While some find that mobile phones increase the efficiency of the value chain (Aker, 2010), others do not find a significant effect on the price farmer get for their products (Fafchamps et al., 2012). In Uganda, there is some evidence that mobile phones may affect the price risk. For instance, Muto et al. (2009) find that mobile phones affect market participation decisions.

The two stacked bar charts on the left in Figure 5 look at the relation between private investment in information gathering technology and intensification behavior. As a proxy of investment in private price risk reduction technology by rice and potato growers in Uganda, we use cell phone ownership. We find that about 73 percent of households in our sample have a mobile phone. The bar charts compare the proportion of households that intensify between those who have invested in risk reducing technology (buy having acquired a mobile phone) and those who did not. We expect to find a relatively larger proportion of households to use fertilizers and/or pesticides when they have a cell phone. This is indeed what we find in Figure 5: about 45 percent of household that report having a mobile phone do not use fertilizer or pesticides. Among the households that do not own a mobile phone, this is more than 60 percent. Especially the share of households that use both pesticides and fertilizers is much higher among households that are better insured against price risk due to their investment in price risk reducing technology.

Figure 5: Private investment in risk reduction



Farmers can also invest in technology to reduce risk of post-harvest losses. This risk is substantial, and in developing countries, most of these losses result from poor on-farm storage practices (Hodges et al., 2011). For rice, post harvest losses due to poor storage can lead to direct losses of up to 30 percent of the harvest. There are also indirect losses through lower prices due to quality issues caused by poor storage. Simple storage technologies such as airtight, reusable plastic bags that protect stored rice from moisture, pests and rats can make a big difference. Potato often rot while stored, and simple investments such as trays or racks that are shaded and aerated reduce rotting substantially.

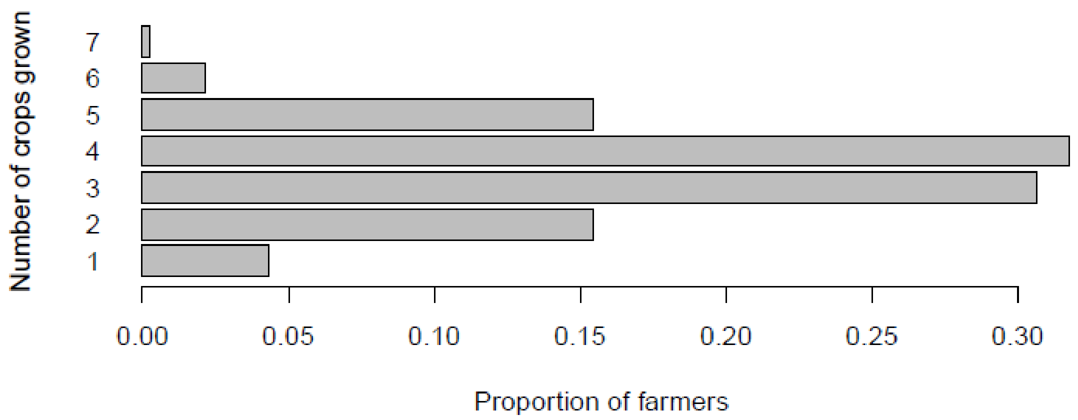
We ask farmers whether they store their potatoes or rice in a special storage facility, as opposed to just on the floor. The results are similar to what we find for investment in information and communication technologies. About 45 percent of households that have improved storage are not using any improved inputs. This share is about 64 percent for households that have no improved storage. We find that storage is especially used together with pesticides: about 27 percent of household that has dedicated storage uses pesticides, fungicides or herbicides. In the subgroup of households that do not have storage this is only 17 percent. This indicates complimentary between pesticides, herbicides and fungicides use and storage.

Diversification

As mentioned above, diversification is also a very important risk management strategy that is used by individuals and households in risky environments. In developing countries, it is often found that people are engaged in different activities, being part time farmer but also engage in crafts making, beer brewing or day laboring (Barrett et al., 2001). At the farm level, risk spreading across different crops with different characteristics in terms of maturing and drought tolerance is also often observed.

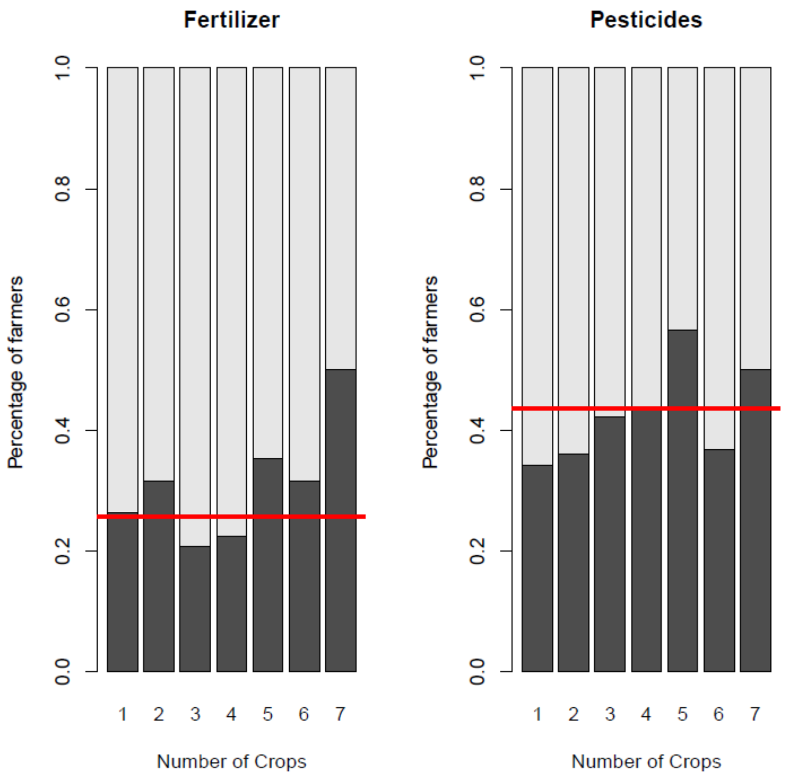
Figure 6 shows the proportion of farmers that grow a particular number of crops (excluding rice/potatoes) in Uganda. More than 60 percent of households in our sample report to be growing 3 or 4 crops in addition to potato or rice they grow. This suggest relatively little specialization and moderate levels of diversification.

Figure 6: Crops Portfolio



We then relate these two indicators of diversification to sustainable intensification practices. We expect that farmers that are better able to deal with risk through higher diversification are more inclined to use fertilizer and pesticides. The first graph in Figure 7 explores the relation between fertilizer use and the number of crops the household grows. The red line indicates that, overall, about 25 percent of households reports using fertilizer. However, the bar charts indicate that this proportion seems to be higher for households that grow more than four crops. The second graph is similar, but looks at the use of pesticides. Here we see that overall, about 43 percent of households are using pesticides/fungicides or herbicides. Here, we find that households that have only one or two crops next to potatoes or rice are less likely to be using improved inputs.

Figure 7: Intensification and diversification



Precautionary Savings

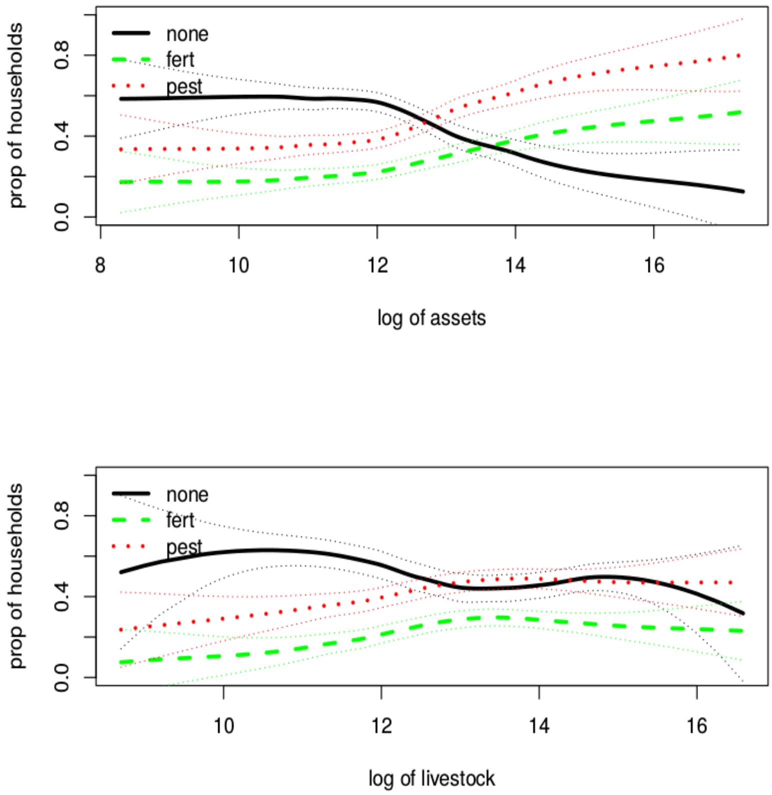
In the absence of credit and insurance markets, savings is probably the most effective way to protect against common shocks (Udry, 1995). Unfortunately, just as credit and insurance, farmers in remote areas often do not have access to savings instruments that are safe and protect against inflation. Therefore, the poor often save in the form of non-financial assets, especially livestock (Rosenzweig et al., 1993a). Selling off these assets to cope with shocks may lead have long run consequences, as productive assets are reduced (Dercon, 2008).

Figure 8 explores the link between precautionary savings in the form of assets and sustainable crop intensification among Ugandan potato and rice farmers. We make a distinction between asset ownership and livestock ownership. The top panel of the graph shows non-parametric regression curves for (logarithm of) assets and the proportion of households that report not using fertilizer or pesticides (solid line). As can be seen, the proportion of households that does not use any inputs is highest at the lower end of the asset distribution. Below logarithm of asset levels of 12 or about UGX160,000, around 60 percent of households do not report using modern inputs[6]. If the logarithm of assets rises above 12 we see a gradual reduction in this proportion. At the logarithm of asset

6 UGX is Ugandan shillings, the local currency. At the time of the survey, USD1=UGX2,600.

levels of around 16, corresponding to assets holdings above 8 million, only about 20 percent of households report not using fertilizer or pesticides. The correspondence between fertilizer and pesticides use are a mirror image of this, with pesticides more widely used overall, and a clear acceleration in use above the 12 threshold.

Figure 8: Precautionary Savings



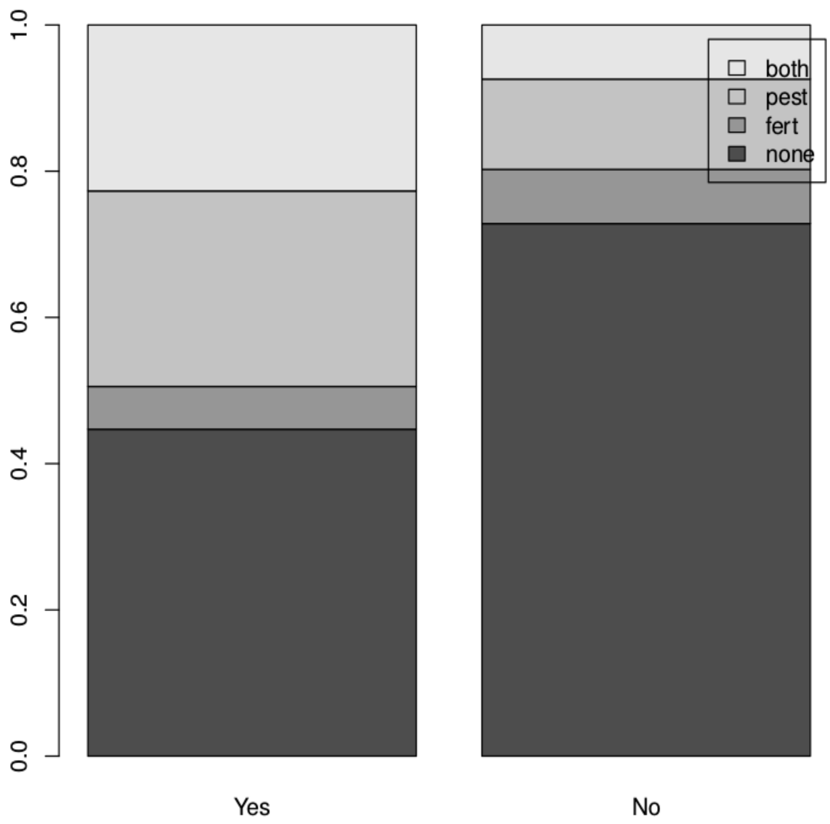
The bottom panel of Figure 8 reports non-parametric regressions for livestock assets. In this figure, most of the action is below logarithm of asset levels of 13 (or about UGX440,000). The proportion of households that use fertilizer increases gradually, from virtually zero to about 30 percent, over a range of livestock assets between 0 and UGX500,000. For pesticides, there is a similar increase from about 20 to 45 percent. Once a household have more than UGX500,000 in livestock assets, the proportions seem to level out.

Access to Credit

The relationship between access to credit and risk has also received some attention in the literature (Eswaran et al., 1989; Udry, 1990). Since credit needs to be paid back, it is closely related to precautionary savings. At the same time, credit is also related to insurance, as it also involves a contract between different parties and hence suffers from the same principal agent problems than insurance contracts. Credit agreements sometimes also include implicit or explicit limited liability clauses, freeing the debtor from its obligation in case of force majeure.

Figure 9 shows that there is a link between intensification behavior and access to credit among Ugandan rice and potato farmers. Among households that report not to have access to credit, only 25 percent state they are using fertilizers, pesticides or both. In the subgroup of households that report they do have access to credit, this proportion increases to about 55 percent. We see that especially the proportion of households that uses both pesticides and fertilizers together increases substantially with access to credit. While it is difficult to establish if this effect is due to relaxing credit constraints or making farmers able to take on more risk, Karlan et al. (2014) find the latter to be the dominating cause in Ghana.

Figure 9: Access to credit



Putting it All Together

In this part, we will analyses the relationship between intensification behavior and and risk management strategies in a more formal and systematic way. We start by looking at the effect of each risk management strategy separately on intensification behavior. In particular, we start by running simple bivariate logistic regressions of the decision to use fertilizer (or pesticides) on each risk management strategy. Obviously, apart from the six risk management strategies we investigate here, there are many other factors that determine intensification behavior. If these other factors are also related to these six risk management strategies in a systematic way, which is likely as our data is not derived from an experiment, the estimate of the role of risk management for intensification behavior will be biased. In particular, the effect of the other factors will be erroneously attributed to the risk management strategy.

One way to try and isolate the true effect from the risk management strategy from the other factors that influence is to control for the other factors, a technique known as selection on observables. This can be done by simply including all the other factors in the regression. We include household characteristics that have been found to influence fertilizer adoption in the literature. In particular, we include household size to reflect differences in labor supply (eg. Marenya et al., 2007). We also include education of the household head to capture the fact that educated individuals may process information about new technologies more quickly and effectively (Foster et al., 2010). Further, we control for the age of the household head to measure experience (eg. Deressa et al., 2009). Gender of the household head is added to capture gender-linked differences in the adoption (eg. Doss et al., 2001).

An alternative way we will try to statistically deal with potential selection bias is through matching estimators. Matching methods estimate treatment effects from observational data by nearest neighbor matching. This is accomplished by imputing missing potential outcomes from (the average) outcomes of similar subjects that receive the other treatment. Similarity is defined on the basis of a set of observable characteristics, as represented by a set of covariates. In our case, we will match on the same covariates we will use in the selection on variables regressions: household size, gender of the household head, age of the household head, education level of the household head and crop[7].

The results of these different models are presented in Table 2. Model (1) present results from the univariate logit regressions with fertilizer use as the dependent variable. Model (4) presents results for the univariate logit regressions with pesticide, herbicides or fungicides use as the dependent variable. As we can see, having storage facilities (Storage) increases the log odds of using both fertilizer and pesticides significantly. Model (2) adds the household characteristics as control

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7 While matching makes the same identifying assumptions as OLS, it generally reduces bias but at the expense of efficiency. We use propensity score matching for binary treatments (*Storage*, *Phone* and *Credit*) and generalized propensity score matching for continuous treatments (*Concentration*, *Assets* and *Livestock*) following Hirano et al. (2005). The former is implemented in stata using *teffects psmatch*, the latter using *doseresponse* (Mattei et al. 2011).

variables in the fertilizer model, while model (5) does the same for pesticides. Storage technology remains significant, albeit only at the 10 percent significance level. Finally, in models (3) and (6), we provide results from a matching estimator. Here we find that storage has no effect on fertilizer use. However, in line with the complementariness we found between storage and pesticides, fungicides and herbicides in the descriptive part, we do find that investing in storage technology significantly increases the odds of using pesticides. The results for having access to a mobile phone (Phone) are similar to those found for storage.

For concentration (Concentration), we find no effect for the regressions with fertilizer as the left hand side variable. In fact, in model (2), when we also control for household characteristics, we find that increased diversification leads to lower intensification, which is contrary to what we expect. For pesticides, the results are in line with our hypothesis that less diversification is more risky, leaving the farmer less space to experiment with modern technologies. This is again in line with what we found in 6 (bottom right panel).

According to expectations, access to credit (Credit) seems to be positively related to fertilizer use. However, the results for the matching estimator suggest the positive effect is due to selection bias confounding the results. The influence of assets on intensification behavior is clear. Precautionary savings in the form of both durable assets (Assets) and livestock assets (Livestock) is an important predictor for both fertilizer and pesticides use.

Table 2: Partial regression models

	fert			*pest*		
	(1)	(2)	(3)	(4)	(5)	(6)
Storage	0.508***	0.352*	0.056	0.606***	0.351*	0.085**
	(0.188)	(0.197)	(0.036)	(0.160)	(0.200)	(0.041)
Phone	0.728***	0.594***	0.067	0.805***	0.690***	0.082**
	(0.196)	(0.208)	(0.060)	(0.163)	(0.197)	(0.039)
Concentration	0.192	0.827*	-0.264	-1.071***	-0.100	-1.240***
	(0.444)	(0.460)	(0.446)	(0.418)	(0.477)	(0.429)
Credit	0.879*	0.481*	0.095**	1.346***	0.630***	0.008
	(0.240)	(0.254)	(0.042)	(0.210)	(0.225)	(0.037)
Assets	0.263***	0.258***	0.254***	0.296***	0.351***	0.281***
	(0.054)	(0.055)	(0.054)	(0.050)	(0.061)	(0.049)
Livestock	0.171***	0.188***	0.179***	0.011	0.210***	0.153***
	(0.059)	(0.068)	(0.063)	(0.011)	(0.066)	(0.053)

*p<0.1; **p<0.05; ***p<0.01

However, it is important to realize that farmers typically rely on different risk management strategies at the same time. We therefore bring everything together in two regression model. Results are reported in Table 3. Model (1) in the table has as a dependent variable a dummy indicator that takes on the value of one if the household reports using fertilizer and zero otherwise. We find that none of the control variables significantly affects the odds of using fertilizer. Private investment in information technology or storage technology also does not seem to influence fertilizer use. Concentration also does not seem to matter to the decision to use fertilizer. Only precautionary savings in the form of assets and access to credit seem to be risk reducing strategies that increase crop intensification through fertilizer application. This seems consistent with model (3) in table 2.

Model (2) in Table3 shows results but for the decision to use pesticides, herbicides of fungicides as the dependent variable. For pesticides, we find that household size has a significant and negative effect. We also find that investment in ICT increases the likelihood of using pesticides. In addition, while our measure of concentration was not significant for the case of fertilizer, it is now. This is consistent with what we find in Figure 6, where we find diversification is positively associated with pesticides applications, but not with fertilizer. Finally, we again find substantial effects from precautionary savings and access to credit.

Table 3: Multivariate regression models

	Dependent variable:	
	fert	pest
	(1)	(2)
Hhsize	−0.045	−0.083***
	(0.032)	(0.029)
Femhead	−0.291	0.110
	(0.283)	(0.241)
Agehead	−0.008	−0.003
	(0.006)	(0.006)
Primary	−0.263	0.377
	(0.327)	(0.301)
Secondary	−0.479	0.308
	(0.365)	(0.336)
Storage	0.255	0.257
	(0.200)	(0.175)
Phone	0.361	0.369*
	(0.222)	(0.192)
Concentration	0.451	−0.898**
	(0.460)	(0.441)
Assets	0.227***	0.246***
	(0.061)	(0.057)
Credit	0.734***	1.212***
	(0.247)	(0.219)
Constant	−4.119***	−4.011***
	(0.838)	(0.786)
Observations	848	848
Log Likelihood	−463.909	−531.621
Akaike Inf. Crit.	949.819	1,085.242
Note:	*p<0.1; **p<0.05; ***p<0.01	

Taken together, our analysis shows there is some correlation between crop intensification and indicators of risk management practices among rice and potato farmers in Uganda. We find that farmers need to have sufficient levels of savings before they engage in pesticide or fertilizer application. However, being able to borrow ex-post through ex-ante access to credit also seems to facilitate pesticide and fertilizer adoption. The ability to spread risk through diversification is positively correlated to intensification, but only for pesticide use. There is some evidence that private investments that reduce exposure to price risk and the risk to post harvest losses are related to pesticide use as well.

Conclusion and Policy Implications

Farm households that have only limited access to insure against risk inherent to rain-fed agriculture tend to prefer safer bets to more risky bets, and they are prepared to pay for this by forgoing higher average returns. In as far as crop intensification, in the form of modern input and technology use in farming, is perceived as more risky than traditional farming, this means a household's willingness to embrace new technologies depends on whether it is willing and able to take on additional risk. Using data from about 900 small-holder potato and rice farmers in Uganda, we investigate if risk is likely to be a barrier to sustainable crop intensification.

We find that intensification, in the form of fertilizer application and pesticides/herbicides/fungicides use works: Households that use the inputs have, on average, higher yields than those that do not. We also find intensification to be profitable: Household that use the inputs have, on average, higher profits than those that do not. Contrary to expectations, using kernel density plots, we do not find that crop intensification increases risk at the bottom end of the distribution. In other words, for any possible outcome in terms of yield x, farmers that use modern inputs always have a higher probability of receiving at least x than farmers who do not use modern inputs.

We also find that farmers that invest in risk reducing technologies, such as storage and information and communications technology, are also more likely to use pesticides. In addition, farmers that report using pesticides are also more diversified. The probability of using crop intensification methods gradually increases with precautionary savings, especially in the form of livestock. Finally, we find that households that report to have access to credit are also more likely to use fertilizer and pesticides.

Policies to should be designed in a holistic way. Farmers are confronted with a myriad of interrelated risks and use a range of interrelated strategies to deal with these risks. Weather outcomes affect demand and supply, and thus also price outcomes. As such, perceived risk related to weather will also affect risk perceptions with respect to prices. Addressing only one source of risk, such as weather risk through provision of index-based insurance may not increase intensification if price risk is not at the same time addressed. On the other hand, the interrelated nature of risk and risk strategies may also lead to policies that reinforce each other. For instance, yield area insurance is likely to increase intensification by directly reducing risk. At the same time, yield area insurance may be considered as sufficient collateral, making micro-finance institutions less hesitant to lend to smallholder farmers. This in turn may lead farmer to intensify more, as credit is also one of the strategies farmers use to manage risk. Policies that affect risk management in one area should therefore also consider the consequences on risk management in other areas. It also means that policies should be designed to address risk at different levels (natural disasters that affect entire regions versus household level shocks such as illness of household members during harvest period) and by different actors (government interventions to reduce aggregate price risk versus private sector actors area-yield based crop insurance).

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