Technology Adoption and Crop Diversity

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Abstract

Uninsured risk is a major obstacle for technology adoption in rural areas of low income countries. Overcoming this obstacle is of particular importance to increasing food production and thus food security in developing countries, where technology such as improved or high value seeds may be available but uptake remains low. In this paper we study to what extent farmers use crop diversity as a self-protection measure against volatile yields. Using both theoretical and empirical models we evaluate whether poor rural households use crop diversity to mitigate risk from cash crop adoption or whether cash crop adoption is a substitute for crop diversity. Our theory predicts that cash crop adoption reduces crop diversity. Using an instrumental variables approach with theoretically derived instruments applied to household panel data from rural Uganda we find that an increase of cash crops by 1 % reduces crop diversity by 0.5 %. These findings caution that policies to increase the uptake of high yielding varieties can lead to a loss of crop diversity. Such policies should consider the

welfare effects of reduced diversity as it relates to food security and the provision of valuable ecosystem services.

1 Introduction

Agricultural is a risky but important source of income in developing countries. Agricultural incomes fluctuate with the weather and international commodity prices. These income fluctuations translate often directly into consumption shocks as financial markets to smooth consumption are widely absent and risk sharing becomes ineffective when income shocks are correlated (Kazianga and Udry 2006). The adoption of cash crops raises rural incomes but adds also risk to the income portfolio(Ashraf et al. 2009). The lack of insurance in poor rural areas leads to low levels of cash crops adoption (Cole et al. 2014; Karlan et al. 2014) which impedes rural development (Dercon and Christiaensen 2011). Traditionally, rural households use crop diversity to reduce the agricultural risk (Benin et al. 2004; Di Falco and Chavas 2009; Bezabih and Sarr 2012). Diversification reduces the income volatility if crop incomes are not perfectly correlated.[1] An increase of cash crop adoption could potentially have two effects on crop diversity. Households may either increase crop diversity to mitigate the risk of cash crop adoption or they could reduce crop diversity as less land is left for diversification. In this paper we address the question whether farmers increase crop diversity to mitigate the risk of cash crop adoption. To analyze the mechanisms that underlay the relation of cash crop adoption and crop diversity we solve a theoretical model of land allocation between N crops under uncertainty. We show that cash crop adoption reduces crop diversity. The mechanisms is that the effect of crop diversity on income variance declines

[1] This mechanism is widely used in portfolio management (Gollier 2001; Elton et al. 2009) and has been studied theoretically in the context of crop diversity and financial integration Quaas and Baumgärtner (2008); Baumgärtner and Quaas (2010) .

with the area allocated to diversity. We show further that expected excess return from cash crops over subsistence crops affect crop diversity only via cash crop adoption. We base our empirical strategy on this result using the panel data of 3000 households from the Living Standards Measurement Study-Integrated Surveys on Agriculture in Uganda (LSMS-ISA). We estimate the effect of cash crop adoption on crop diversification using lagged excess returns as instruments for cash crop adoption in a structural Tobit equation Wooldridge (2002, Ch. 17.6). Our empirical results show that a one percent increase in the area under cash crops reduces crop diversity by 0.3 to 0.5 percent depending on the measurement of crop diversity. These finding are in line with a previous study of Brush et al. (1992) who show that cash crop adoption reduces the diversity of traditional crop varieties.[2] In contrast Isakson (2011) found a positive impact of cash crop adoption on crop diversity. The differences in these findings may be partly explained by their different ability to address omitted variable bias and the endogeneity of cash crop adoption that emerges from the simultaneity of the decisions. The main contribution of this paper is to interpret the findings in light of adoption to risk. We are further able to address the simultaneity problem and to control for omitted variable bias.

Our results caution that policies which encourage the adoption of high yielding varieties reduce crop diversity. A loss of crop diversity may affect food security, ecosystem services such as pollination and pest control and the option value of crop diversity. In many rural areas of developing countries there are strong rural networks for informal insurance (Townsend 1994; De Weerdt and Dercon 2006; Fafchamps and Gubert 2007; Mobarak and Rosenzweig 2013). An increase of cash crop adoption and a reduction of crop diversity can increase the covariance of household incomes and therefore reduce the functioning of these insurance networks with severe

[2]See also Coromaldi et al. (2015) for a recent study with similar results.

consequences for food security.

2 Model

Consider a rural household that has to decide on the number of subsistence crops N and the share of land that it allocates to cash crops $0 \leq A \leq X$ where A is the land allocated to cash crops and X is the total land endowment. All available subsistence crops have constant marginal net revenues per unit of land. All have equal expected marginal net revenues π_s with variances σ_s^2. Further we assume that the covariance of yields is zero for any pair of subsistence crops, and equal to ρ between any subsistence crop and the cash crop. This simplification exaggerates the effect of diversification on portfolio variance in case of a positive covariance between subsistence crops and understates it otherwise. By symmetry, each subsistence crop will be grown on the same amount of land, $(X - A)/N$.

The expected marginal net revenues of the cash crop is given by π_c with variance σ_c^2. To include the riskiness of technology adoption in our model we assume that

$$\sigma_c > \sigma_s. \tag{1}$$

Based on these assumptions, the variance of the whole crop portfolio is

$$\sigma^2 = \frac{(X-A)^2}{N}\sigma_s^2 + A^2\sigma_c^2 + A(X-A)\rho, \tag{2}$$

where the first term on the right hand side (RHS) is the variance of the subsistence crop portfolio, the second term on the RHS is the variance of the cash crop and the last term on the RHS is the covariance between the cash crop and the subsistence crops. Growing an extra variety of subsistence crops involves a fixed cost, γ.[3] Assuming mean-variance preferences and

[3] An alternative explanation is that the expected profits of crops differ. Under the assumption of equal variance, the household plants the crops with the highest expected re-

using η to denote the household's coefficient of absolute risk aversion, the household's optimization problem is

$$\max_{A,N} \left\{ A\,\pi_c + (X - A)\,\pi_s - N\gamma - \frac{\eta}{2}\sigma^2 \right\}. \tag{3}$$

The first-order conditions for expected utility maximization can be written as

$$\frac{\eta}{2}\left[-\frac{2(X-A)}{N}\sigma_s^2 + 2A\sigma_c^2 + (X-2A)\rho\right] = \pi_c - \pi_s$$
$$\frac{\eta}{2}\left[\frac{\sigma_s^2(X-A)^2}{N^2}\right] = \gamma.$$

The sufficiency conditions are fulfilled under Assumption (1) (see Appendix A). Solving the first order conditions for N yields

$$N = (X - A)\sqrt{\frac{\eta\sigma_s^2}{2\gamma}}. \tag{4}$$

where A is given by

$$A = \max\left\{ \min\left\{ \frac{\pi_c - \pi_s + \sqrt{2\eta\gamma\sigma_s^2} - \frac{1}{2}\eta\rho X}{\eta(\sigma_c^2 - \rho)}, X \right\}, 0 \right\}. \tag{5}$$

From equation (4) follows that optimal subsistence crop diversity declines in cash crop adoption and increases in total land endowment. We use these two equations in Section 5 to derive an estimation strategy.

Equations (4) and (5) also show that subsistence crop diversity increases in total land endowment, which is a consequence of the fixed costs of growing extra varieties. Equation (5) indicates that corner solutions are well possible. A farm household may fully specialize in cash crop production, i.e. choose $A = X$, if the degree of risk aversion η is small enough and the expected yield of the cash crop is sufficiently larger than the expected yield of

turns. Adding more crops to the portfolio would therefore reduce the expected return of the portfolio. Although this scenario seem more compelling it complicates the analysis by introducing unequal distribution of land among subsistence crops.

the subsistence crops. On the other hand, a farm household that is characterized by a high degree of risk aversion may also specialize in subsistence crops, in particular if the gain in expected yield is small and the increase in risk due to the covariance of cash crop with subsistence crops is large. For a household that maintains a limited amount subsistence crop production, cash crop adoption decreases in total land endowment. This result may seem surprising as we would expect that the more land a household posses the more it can allocate to cash crops without risking the supply of subsistence crops. The negative relation between cash crop adoption and total land endowment stems from the assumption of fixed costs for subsistence crop diversity. In our specification the costs of risk reduction through subsistence crop diversity declines with land allocated to subsistence crops.

3 Data

For our empirical analysis we use the data of the Living Standards Measurement Study Integrated Surveys on Agriculture in Uganda (LSMS-ISA). The data contain three rounds of interviews from 2009/2010 to 2011/2011 of 3200 households. For each year, data are collected for two cropping seasons and we use both seasons as separate observations. The sample is representative on national, rural and urban and on regional level. Field sizes have been validated with GPS measurements. In the following we limit our analysis to the rural sample with possession of agricultural land.

To compare outputs we computed gross revenues (price $\times$ quantity). When prices were missing because goods were not traded we use median village prices for the commodity in a given season if they were available. If the good was not traded in the village in the respective season we used the median seasonal district price to evaluate outputs. Because of this procedure the revenues of subsistence crops are less accurate than the revenues of cash crops are more prices are extrapolated. Subsistence crop revenues may be biased upwards if households sell only subsistence crops when prices are high or they sell only the small share of the harvest with the best quality such that prices are biased upwards. Households may also sell the excess harvest which they cannot consume. This may happen in times when prices are low because of the large supply such that prices are biased downwards. If these biases are consistent across years they do not affect our results as we are only concerned about the relative changes of cash crop revenues in comparison to subsistence crops revenues. Further, we do not use net revenues as most inputs such as family labor are not traded and the allocation of inputs between different crops is often unclear. Subtracting costs would therefore increase the sampling error. We convert all values in 2011 USD purchasing power parity from the World Bank.

4 Summary Statistics

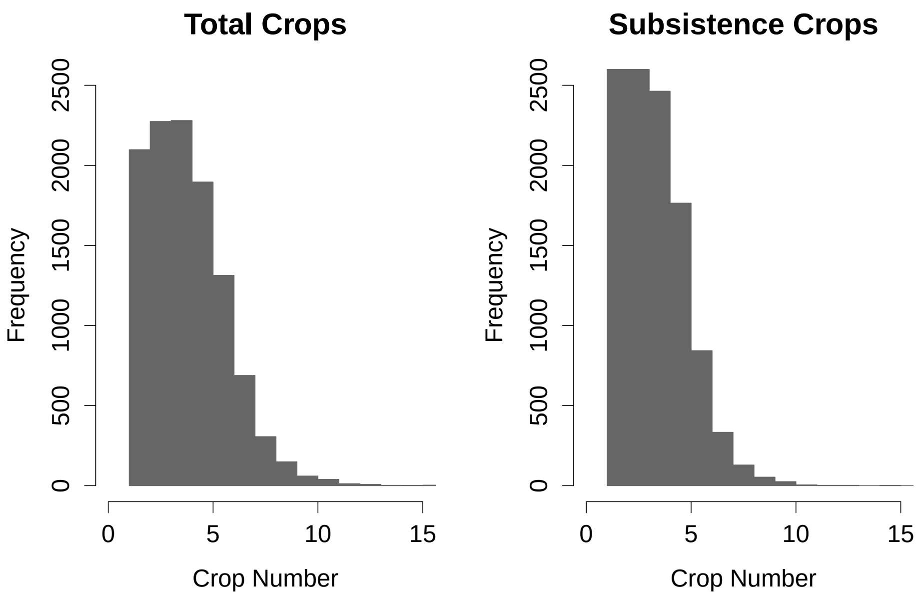
Table 4 summarizes the main variables of our study. It shows the mean, the standard deviation and the first second and third quantile of total land area per household in hectare [ha], cash crop area per household in ha, crop revenues in USD per ha, and the number of all crops and of subsistence crops per household. The total number of observations is 11,129. Several impor-

Table 1: Summary Statistics

	Mean	SD	q25	q50	q75
Area [ha]	7.7	22.9	2.5	4.6	7.9
Cash crop area [ha]	1.0	6.3	0	0	0.7
Cash crop revenues [USD/ha]	640	4440	50	130	350
Subsistence crop revenues [USD/ha]	280	1850	60	120	230
Crop number	4.2	1.9	3.0	4.0	5.0
Subsistence crop number	3.7	1.6	3.0	4.0	5.0

tant observations can be made from the summary statistics. The first is that only less than half of the population has adopted cash crops. The second is that the mean and the variance of cash crop revenues is larger than the variance of subsistence crops revenues as expected. This observation becomes obvious from the mean and the standard deviation (SD) of cash and subsistence crop revenues and by comparing the first and last quantile of revenues. Lastly, Table 4 suggests that cash crops do not play a large role for total crop diversity. Figure 1 gives a more detailed picture of the distribution of crop diversity per household. It shows that the distributions

Figure 1: Crop Diversity



differ mainly in the lower quantiles which suggest that households with cash crops are mainly specialized in few crops.

5 Estimation

The whole section has to be redone based on Wooldridge (2002, Ch 17.5 & 17.6).

Based on the first term of equation (4), crop diversity is a linear function of land allocated to cash crops and total land size. To empirically test our theoretical results, we therefore estimate

$$\text{diversity}_{it} = \alpha_1 \text{ cash crops}_{it} + \alpha_2 \text{ land}_{it} + \text{season}_t + \text{year}_t + \gamma_i + \varepsilon_{it} \quad (6)$$

where 'diversity_{it}' is crop diversity of household i at time t. The regressors are land under cash crops (cash crops_{it}) and total land endowment (land_{it}) of household i at time t. We further include season dummies, a linear time trend and household fixed effects. Thus, the model is identified from within household deviations in cash crop adoption and land endowement after controlling for year and season shocks shared by all households. For the estimator to be unbiased, the covariates must be uncorrelated with the error term. However, crop adoption and crop diversity may be simultaneously determined, and if so, our results would be biased. Instrumenting for cash crop adoption can overcome this empirical challenge. Equation (5) suggests expected excess returns as instruments for cash crop adoption which we use in a second specification.

We define **cash crops** as crops of which more than 50% of the output is traded on markets. This threshold to define cash crops is relatively low because parts of the harvest may not be sold for other reasons than self-consumption (e.g. trade, storage, feed??). We test the impact of the threshold on the results in the robustness section.

Crop diversity in our model is defined as the number of subsistence crops. We therefore use the number of subsistence crops in our preferred specification with subsistence crops defined as all crops that are not cash crops. However, in reality households may also diversify with cash crops.

We compare the results of subsistence crop diversity to the results with total crop diversity as response variable. The number of crops can be misleading if land is allocated unequal among crops. This was ruled out in our theoretical model by the assumption of equal profits and equal variance. In reality expected profits and the variance of subsistence crops may differ such that the optimal land allocation is not equal across subsistence crops. To account for this effect we use the inverse Simpson or Herfindahl–Hirschman Index with all crops and subsistence crops as an alternative specification of crop diversity and compare the results with this measure to the results with crop numbers in the robustness section.

The **expected excess returns** is the expected return on cash crops per hectare (ha) minus the expected return on subsistence crops per ha. According to equations (5) and (4) it affects crop diversity only through cash crop adoption. However, we cannot observe it directly because observed excess returns may differ from expectations and we cannot observe excess returns for households with corner solutions or extreme excess returns. Households with very low expected excess returns allocate all land to subsistence crops while households with very high expected excess returns may specialize in cash crop production. As rural households in poor countries have very little possibility to forecast weather and market developments that determine the expected returns, they may base their expectation on their experience. We therefore use the lagged median district gross revenues per ha from the last two seasons as instruments for cash crop adoption. These instruments are unbiased if the inter-temporal variance of expected excess returns is driven by factors that vary only at the district level such as crop prices or weather anomalies. We use the gross returns instead of the net returns to generate the predicted excess returns as production costs are particular difficult to measure in rural areas of developing countries as many inputs such as family labor are not traded on the market and factor allocation among crops is difficult to trace. Further, we use the district as aggregation level as the district is the smallest geographical unit for which we have enough observations. Further, as we use households fixed effects we are only concerned about changes and not levels of expected excess returns. As these changes are mainly governed by weather anomalies, price fluctuations and pest outbreaks we think that the district is the relevant level of comparison.[4] To control for the seasonality we interact the lagged district revenues with seasonal dummies.

Lastly, we transform all values by inverse hyperbolic sine transformation (ihs) (Burbidge et al. 1988) to account for the skewed distributions and and the high incidence of zero values.

6 Results

Table 2 presents the impact of cash crop adoption on crop diversity. The first two columns show the results for subsistence crop number while the last two columns show the results for the number of all crops as response variable. We compare the OLS estimates with the IV approach with lagged cash and subsistence crop revenues as instruments. As we use ihs transformed values on both sides such that the coefficients can be interpreted as elasticities.

The results show that cash crop adoption reduces subsistence crop diversity. An increase of the cash crop area by one percent reduce the number of subsistence crops by 0.1 percent in the OLS specification and by 1.6 % in the IV specification. An increase of the cash crop area by 1 % increases the total number of crops by 0.05 % in the OLS specification and it reduces crop diversity by 1.4 % in the IV specification. However, the F statistic for the instruments is 17.4 but we loose more than half of the observations in the IV specification because of time gaps in the survey which leaves some lagged

[4] There are 111 districts in Uganda with an average size of 2200 km^2.

Table 2: Crop Numbers and Cash Crop Adoption

	ihs(Subsistence Crop Number)		ihs(Total Crop Number)	
	OLS	IV	OLS	IV
ihs(Cash.Area)	-0.086^{***}	-0.473^{***}	0.053^{***}	-0.330^{***}
	(0.011)	(0.113)	(0.012)	(0.098)
ihs(Area)	0.223^{***}	0.355^{***}	0.198^{***}	0.330^{***}
	(0.016)	(0.048)	(0.016)	(0.044)
Observations	14,571	5,982	14,639	6,021

Notes: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

revenues unspecified.

7 Robustness

In this section we test the robustness of the results with respect to the threshold that defines cash crops and with respect to the diversity measure. To test the robustness of the results with respect to the definition of cash crops we run the same regressions with a market share threshold to define cash crops of 75 %. The results for subsistence crop numbers and cash crop adoption are given in Table 3.

Table 3: Crop Numbers and Cash Crop Adoption

	ihs(Subsistence Crop Number)		ihs(Total Crop Number)	
	OLS	IV	OLS	IV
ihs(Cash.Area)	-0.099^{***}	-0.563^{***}	0.028^{**}	-0.403^{***}
	(0.013)	(0.143)	(0.013)	(0.116)
ihs(Area)	0.224^{***}	0.345^{***}	0.207^{***}	0.320^{***}
	(0.015)	(0.052)	(0.015)	(0.046)
Observations	14,591	5,504	14,639	5,537

Notes: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

The coefficients for cash crop adoption are smaller (larger in absolute terms) than the ones reported in Table 2 but very similar in magnitude.

Next, we test the effect of the diversity measure on the results but with the same thresholds to define cash crops as in Section 6. Instead of subsistence crop and total crop numbers we use subsistence and total crop diversity, measured with the inverse Herfindahl index. The results are given in Table 4.

Table 4: Crop Diversity and Cash Crop Adoption

	ihs(Subsistence Crop Diversity)		ihs(Total Crop Diversity)	
	OLS	IV	OLS	IV
ihs(Cash.Area)	-0.026^{**}	-0.392^{***}	0.066^{***}	-0.284^{***}
	(0.013)	(0.111)	(0.014)	(0.094)
ihs(Area)	0.079^{***}	0.192^{***}	0.055^{***}	0.163^{***}
	(0.018)	(0.053)	(0.017)	(0.049)
Observations	14,571	5,982	14,639	6,021

Notes: ***Significant at the 1 percent level.
**Significant at the 5 percent level.
*Significant at the 10 percent level.

Again, the results are very similar to the ones reported in Table 2 but the coefficients are slightly larger.

8 Discussion

We have shown theoretically that cash crop adoption reduces crop diversity. The mechanism is that the impact of crop diversity on income variance declines with the area set aside for diversification while the cost for diversification remain constant. This mechanism depends on two assumptions. Firstly, households value only the first two moments of income distribution and secondly the costs for diversification are constant. In reality individuals may also care about the skewness of income distribution and in fact individuals are shown to be downside risk averse Deaton (1992); Gollier (2001); Di Falco and Chavas (2009). Further it seems reasonable that the costs for diversification consist of a fixed and a variable part. Households may need special tools or knowledge for new crops which may be area independent but they may also except reduced returns from planting additional lower yielding varieties. We cannot predict the impact of these assumptions on our results but the empirical analysis supports our theoretical predictions.

The loss of crop diversity has negative externalities on ecosystem service provision such as the loss of pollinating services or an increase of pest outbreaks. A second consequence of crop diversity loss that we want to draw the attention to is the impact on food security.[5] Households make their crop choices given the crop choices of the other households. There is high informal insurance among household members (Townsend 1994; De Weerdt and Dercon 2006; Fafchamps and Gubert 2007; Mobarak and Rosenzweig 2013). An increase of cash crop adoption and a reduction of crop diversity may increase the covariance of household incomes and my therefore reduce the functioning of these insurance networks against covariate shocks.

[5]The option value of crop diversity for food production is well known.

A Sufficiency Conditions

The sufficiency conditions are

$$-\eta(X-A)^2\sigma_s^2 \leq 0 \tag{7}$$

$$-\frac{\sigma_s^2}{N} - \sigma_c^2 + \rho \leq 0 \tag{8}$$

$$\left[\frac{\sigma_s^2}{N} + \sigma_c^2 - \rho\right]\left[\frac{(X-A)}{N}\right] \geq -\frac{1}{2}. \tag{9}$$

The first condition is always fulfilled while the second condition holds because of assumption (1). The last condition holds if the second condition holds.

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