Agricultural Practices and Environmental Degradation

The Case of GM Corn in the Philippines[1]

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ABSTRACT

Improved seeds varieties have led to an increase in agricultural production as well as to a change in agricultural practices and input use. A side effect of these changes that has received little attention to date is the impact of those new technologies on environmental degradation. Using an original survey method of 447 farming households of the Philippine island of Mindanao covering the past ten years, this paper finds a positive correlation between biotech corn cultivation and landslide occurrence, which cannot be explained by an endogenous allocation of crops on plots. Looking at the earth science literature and investigating mediating effects of the slope, it presents suggestive evidence that increased use of herbicide on biotech corn as well as cultivation on very steep slopes are the most likely mechanisms behind this result. Looking at the distribution of landslides as a function of wealth, landslides are found to increase socio-economic inequality by affecting most households similarly, except for the top tail of the landholding distribution.

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Table of contents

1. Introduction

Soil erosion has become a major concern for policy makers over the past decades. According to the FAO's 2015 report on the Status of the World's Soil Resources,

> *"Human pressures on soil resources are reaching critical limits. Further loss of productive soils will amplify food-price volatility and potentially send millions of people into poverty. (...) While there is cause for optimism in some regions, the majority of the world's soil resources are in only fair, poor or very poor condition."* (FAO 2015)

Agricultural activity is one of the key drivers of soil erosion and the cultivation of row crops, such as corn, is notable for inducing erosion (Pimentel 2006).

This paper examines the relationship between agricultural practices and an acute form of water erosion, landslides, in a mountainous region of the Philippines. In this country, water erosion is the main source of soil degradation and is seen as a major threat to the country's food security. Tropical climate associated with heavy rains and frequent violent storms, as well as a high population density induce a strong pressure on the country's agricultural lands. According to the FAO (2015), 10 million ha, corresponding to 38% of the total country area, are moderately to extremely affected by water erosion.

In the hope of increasing agricultural output and improving farmers' livelihoods, the country authorized in 2003 the cultivation of genetically modified (GMO) corn. The majority of corn crops grown in the country over the past fifteen years therefore exhibit either pest resistance and/or herbicide resistance acquired through genetic engineering. The presence of these traits have induced a change in the type and quantity of inputs used by farmers, decreasing the amount of pesticide used but increasing the amount of herbicide.

Using recall data covering the past ten years, collected among 447 farming households on the island of Mindanao, I am able to reconstruct the recent history of the farms, including information on crops cultivated, land use and extreme weather events. Over the past decade, 35 percent of the surveyed plots have been hit by a landslide. Controlling for year and plot fixed effects, I find that growing biotech corn is associated with a significant increase in landslide occurrence compared to other crops and alternative corn varieties. This difference cannot be explained by an endogenous allocation of crops on plots and is robust to inverse probability weighting matching method and a series of restricted sub-sample analyses. Looking at the earth science literature, I find suggestive evidence that increased use of herbicide on biotech corn is a potential mechanism to explain this relationship.

I then investigate how slope and extreme weather events – typhoons – interact with the type of crop cultivated and the probability of landslides. As expected, the occurrence of typhoons has a strong positive influence on the occurrence of landslides, especially when the crop is planted on a steep slope. The difference in landslide occurrence between biotech corn and the main alternative variety becomes significant only when the slope is very steep.

Finally, I look at the distribution of landslide occurrence and as a function of the size of landholdings, which serves as a proxy for wealth. I find that landslides equally affect most households, except for the top tail of the landholding distribution. The poorer households are therefore relatively more exposed to this environmental risk, but the poorest of the poor do not suffer more than the median individual.

This paper contributes to the literature of environmental economics in developing countries (Greenstone & Kelsey 2015) as landslides cause siltation of river and decrease soil fertility. Moreover, it is related to the literature investigating the impact of climate change (Dell et al. 2014), as extreme weather events are likely to become more and more frequent in time as well as to the literature looking at the distributional impact of environmental degradation (Tol et al. 2004, Ibarrarán et al. 2009). Finally, it is also related to the literature in agricultural economics looking at the impact of improved agricultural technologies on the livelihood of farmers in developing countries (Klümper & Qaim 2014, Qaim 2016, Brookes & Barfoot, 2018).

The next section presents background information regarding corn cultivation in the Philippines, the study area and gives some information on the type of landslides that are relevant for this work. Section 3 presents the data while section 4 details my main result and explores potential mechanisms. Section 5 then discusses potential future trends and the distribution of affected households. Section 6 concludes.

2. Background

a. Corn in the Philippines

Corn is the second most common crop in the Philippines after rice, accounting for 12.5% of the total agricultural production value in 2016 (PSA 2016). White corn accounts for 23% of the total output and is traditionally consumed by the farmers themselves or sold on the local market as an alternative to rice. Yellow corn accounts for the rest of the production and is primarily sold to the animal feed industry. (PSA 2018). Most of the corn production is rainfed and located in lowlands, upland plans and rolling-to-hilly areas. Corn growing period lasts four months and there are two production seasons per year: a wet season between April and September and a dry one between October and April. In some areas of the country, a third cropping can be grown if rainfall is sufficient. For more information on corn growing in the Philippines, see Connor (2017).

Filipino farmers have an average landholding of 1.29 ha and 92% have one or two parcels of land (PSA 2015). Poverty incidence is high among farmers and even higher among corn farmers, with poverty headcount ratios of 47.9% and 64.1 % respectively, compared to a national rate of 26.5% in 2009 (Reyes et al 2012).

In 2003, the Philippines authorized the cultivation of genetically modified corn with the Bt trait (Bacillus thuringiensis, pest tolerance) as a way of increasing the yields, farmer's income and to decrease the country's dependency on foreign exports. This was followed, three years later, by the commercialization of stacked traits Bt/Ht, which now account for 94.5% of the biotech corn in the country. Many studies have documented positive effects of Bt crops on yields and farm profits around the world (see Qaim 2016 for a review and a meta-analysis). Yorobe & Smale (2012) and Jones et al. (2017) find a similar pattern in the case of Bt corn in the Philippines. Brookes & Barfoot (2018) estimate the farm–level economic benefit of biotech corn cultivation between 2003 and 2016 at US$724 million.

GMO adoption happened relatively fast in the Philippines: the area under cultivation increased by 5% every year, reaching 62% of the hectarage devoted to corn in 2014, with over 800,000 ha. This figure remained stable until 2016 but then declined sharply in 2017 to 642,000 ha, corresponding to a drop in adoption rate of almost 20 percentage points. This decrease appears to be largely due to the spread of counterfeit seeds locally known as "*ukay-ukay*" and "*sige-sige*" (ISAAA 2017).

b. Study area – The Upper Pulangi Valley

The data used in this paper was collected in the province of Bukidnon, in an area locally known as the Upper Pulangi Valley. The province of Bukidnon is a plateau in the center of the island of Mindanao (South) and its name litteraly means "People of the mountain". Due to its remote location, the province has little attention from the central government and, over the past century, the power has slowly shifted from the hands of traditional leaders to those of big landowners. For a detailed history of the province, see (Edgerton & Edgerton 2008).

The Upper Pulangi catchment is a valley at the eastern edge of the plateau and forms the headwaters of the Rio Grande de Mindanao, the largest river system of the island. Until the 1950s, the area was heavily forested and secluded from the rest of the world, serving as a refuge for the locals against violence committed by the Spanish and American colonial powers and by the Japanese troops during World War II. The population of the valley consisted of a few Lumad tribes, a series of nomadic indigenous groups practicing swidden agriculture. In the 1960s, logging companies were granted concession rights in the region and started opening roads and cutting down the forest. The creation of the roads allowed the arrival of economic migrants from the Visaya archipelago, located in the center of the Philippines. The migrants who were already embedded in the market economy cleared the land and introduced sedentary agriculture of corn, rice and other commodities. This process of land encroachment continues nowadays in the upper parts of the valley, making of the Upper Pulangi one of the last frontier regions of the Philippines.

Despite its proximity with the province capital Malaybalay, a weak presence of the state and a high level of insecurity caused by the New People's Army (NPA) characterize the area. This communist uprising started in 1969 continues to this day, with occasional raids on local population and encounters with the Armed Forces of the Philippines. President Duterte's claim in July 2017 that he would bomb indigenous schools, which he accused of training rebels, has recently increased the local population's feeling of insecurity (Associated Press 2017).

In 2017, the poverty rate in the area was 79% and only 55% of households had access to electricity. The population of the area was ethnically diverse, equally divided between indigenous people and migrants (NHTS, 2017). Corn is the major crop grown, with some area devoted to rice, rubber and other high-value crops (vegetables, hemp …). Despite dramatic improvements in transportation infrastructure over the past ten years, many farmers still sell their harvest to private traders and have limited access to agricultural supplies stores and banking facilities.

Illegal *sige-sige* seeds are endemic in the region, both yellow and white corn, and are cultivated by a large majority of smallholder farmers. These seeds are sold through an underground market and are more generally exchanged between relatives, friends and neighbors. Contrary to reports in the media presenting these seeds as a recent phenomenon (Arcalas, 2018), some farmers in the Upper Pulangi claim to have started cultivating them as early as 2005. The actual origin of this variety remains unclear but according to several interviews conducted by the author, it was created by a former employee of Monsanto Philippines who stole mother seeds from his company and crossed them with a local white corn variety. Although the Bt trait appears to have disappeared over time, *sige-sige* corn still presents a high resistance to glyphosate, allowing the farmers to spray herbicide on their crop without paying the higher price of proper Ht seeds. Moreover, as this resistance appears to be stable across generation, farmers usually save some of their seeds and replant them in the following season (*sige-sige* means "follow-follow").

As in many other developing countries, these counterfeit seeds are less productive than proper biotech seeds. However, in this case, farmers are very much aware of this productivity gap. To the best of our knowledge, sige-sige seeds are never fraudulently sold as branded seeds and there does not seem to be an informational problem at play in this context, as has been documented in other parts of the world (Ashour et al. 2016, Bold et al. 2017). Many farmers declare that, absent financial constraints, they would rather plant proper biotech corn.

c. Landslides

The term landslides covers a set of complex and diverse phenomena that involve the "movement of a mass or rock, debris or earth down a slope" (Cruden & Varnes 1996). Varnes (1978) proposes a classification of slope movements depending on the type of movement and the type of material involved. According to this classification, revised by Cruden & Varnes (1996) and Hungr, Leroueil, & Picarelli (2014)**,** the type of landslides relevant for this study are Earth slumps and are characterized by a rotational sliding of earth (see Appendix 1 for photographic examples). They are associated with slopes ranging between 20 and 40 degrees (between 36% and 83%) and are triggered by intense and/or sustained rainfall leading to the saturation of the soil (Highland & Bobrowsky, 2008).

The size and damage caused by such landslides vary greatly. In our case, their extent is typically limited to less than one hectare and the damaged area rarely exceeds the limits of the plot under cultivation. Despite a high occurrence in the research area, we are unaware of any human fatality caused by landslides over the past years.

3. Data and descriptive statistics

The data used in this paper was collected between April and August 2018 in 14 villages from the province of Bukidnon on the island of Mindanao. In total, 444 households were interviewed. We interviewed farmers who had been active in corn farming at some point over the past 10 years and who were using less than 10 ha of land. We added this restriction to focus on smallholder farmers and for practical reasons given that our questionnaire was not built for large landowners.

With the help of the respondent, the enumerator drew a timeline of the past 10-year history of the farm at the beginning of each interview. This timeline included information such as plots cultivated, land transfers, crops and corn varieties grown as well as major agricultural shocks such as landslides and crop losses. Examples of such timelines can be found in Appendix 2.

This information allowed us to construct an unbalanced panel dataset of 631 plots, covering the 2008-2017 period, totaling 4,684 plot-year observations. Given that we interviewed farmers, we have information on the plots after they acquired them or after they started their farming activity and we did not ask about how the land was used before. Moreover, we only asked detailed questions for the plots that were effectively used or left fallow by the farmer and for this paper, I do not consider those rented or pawned to other households.

We decided to divide corn varieties into three broad categories to match the reality of the field and the way farmers refer to the seeds they plant. The first category is "GMO corn" refers to the biotech Bt/Gt seeds of yellow corn, sold in agricultural supplies stores. "Sige-sige corn" refers to the illegal Gt seeds both white and yellow. "Non-GM corn" covers all open-pollinated or hybrid varieties that do not present either Bt or Gt traits. Finally, in this paper, all the other crops are grouped in a residual category.

Tables 1A and 1B respectively present the descriptive statistics for the panel and cross-sectional plot data. The average size of the plot, as reported by the farmer is 1.5 ha and the mean slope is 45%, corresponding to a 24-degree angle. The slope of the plot was not measured on the field but reported by the farmer. This choice is extensively discussed in the third part of the Results section.

GMO corn adoption is relatively low in the area, with only 33% of plots planted with those seeds at some point over the past 10 years, exactly half the proportion of plots planted in sige-sige. Landslides, on the other hand, are very common, with 35.8% of the plots affected at some point over the past 10 years.

[INSERT TABLE 1 HERE]

Looking at the panel data, GMO and sige-sige corn account for 21.2% and 48.3% of year-plot cells respectively. Plots are left fallow 10% of the time and planted in other crops 13% of the time. The probability that a plot is hit by a landslide during any single year over the past 10 year was 6.3%. Following a landslide, farmers wait on average one year before replanting on the affected area. In 76% of the time, they do not wait and replant the following season. The majority of the landslides are small, with a median area of 0.25 ha, as reported by the farmers. Finally, most households own and cultivate only one plot of land.

The evolution of the relative share of land occupied by each crop category is presented in Figure 1. In 2008, the cultivated area was almost equally divided between the each category. Over time, the share of GMO corn and other crops remained more or less stable while that of sige-sige corn increased at the expense of the open-pollinated (OPV) and hybrid varieties, which had almost disappeared from the fields by the time the data was collected.

[INSERT FIGURE 1 HERE]

Figure 2 presents the repartition of crops in the whole sample and when we restrict it to the landslide occurrences. Even though the share of Sige-sige and non-GM corn remains roughly similar across both graphs, GMO corn is over-represented in the second graph and accounts for one third of all landslides. In the rest of this paper, I show that this correlation is robust to a series of controls, fixed effects and is not caused by a change in the land under cultivation. I then present potential mechanisms and decompose this effect using the slope of the plot and exogenous weather shocks.

[INSERT FIGURE 2 HERE]

4. Results

The empirical strategy I use is a straightforward fixed effects model. More specifically, I estimate the equation:

$$landslide_{ijt} = \alpha + \beta_1 crop_{ijt} + \gamma_t + \theta_j + \epsilon_{it} \qquad (1)$$

Where $landslide_{ijt}$ is a dummy variable equal to one if the plot i from village j was hit by a landslide during year t, divided by the size of the plot, to take into account the fact that larger plots are mechanically more likely to be hit by a landslide. $Crop_{ijt}$ is a vector of dummy variables, each representing a category of crops and equal to one if the crop was planted on plot j at time t. γ_t represents year fixed effects and θ_j the village fixed effect. In some specifications, this village fixed effect is replaced by a household fixed effect or a plot fixed-effect.

Using household fixed effects allows to control for any time-invariant farmer characteristics but does not rule out the possibility that the results are driven by a reallocation of crops within a household. However, given that most households only have one plot, this reallocation is unlikely to bias the results. I still address this issue in four different ways: (i) using plot fixed effects, (ii) restricting my sample to households who only use one plot of land, (iii) restricting to plots who have been planted in GMO corn at some point over the past 10 years and (iv) restricting to plots who were already farmed before 2002. All standard errors are clustered at the household level.

a. Landslides and GMO

The results of the estimation of model (1) are presented in Table 2. Columns (1) to (3) show that plots planted in corn are more likely to be hit by a landslide than when they are left fallow or planted in another crop. This point estimate decreases slightly with the inclusion of household and plot fixed effects but remains highly significant. Planting a crop in corn is associated with a 4.8 percentage point increase in the probability of having a landslide per hectare. This result is consistent with the agronomic literature showing that corn cultivation increases erosion.

Columns (4) – (6) compare the different corn varieties with other land use (land fallow or planted in other crops). Each type of corn is associated with an increase in the occurrence of landslide but there is some heterogeneity between categories. The coefficient of GMO corn is always higher than the others and is statistically different from that of Sige-sige corn in the specifications including household and plot fixed effects.

[INSERT TABLE 2 HERE]

The results of column (6) imply that a given plot is more likely to experience a landslide when it is planted in GMO corn than in Sige-sige corn. This effect does not seem to be driven by the fact that GMO corn is planted on plots that are more likely to be hit by a landslide. To the contrary, if this were the case, the difference between GMO and other corn varieties should decrease with the introduction of the plot fixed effect.

The last three columns present additional evidence that the effect is not driven by an endogenous selection of plot and crop. Column (7) restricts the sample to households who have only cultivated one plot of land over the past 10 years and who therefore did not decide simultaneously which variety to grow on which plot of land. Column (8) only takes into accounts the plots that have been planted in GMO corn at some point over the past 10 years. This way, we are left with the plots that have been selected into GMO cultivation. Finally, column (9) restricts the sample to the plots that started to be cultivated by the farmer before the introduction of biotech corn. As a result, the effect cannot be due to the expansion of land under cultivation following the adoption of GMO corn. In all three specifications, despite the reduction in sample size, the results are remarkably robust and the coefficient of GMO corn is statistically different from that of Sige-sige corn.

Similar results are obtained with inverse-probability weighting method, using farmer's characteristics (age, education, ethnicity, number of plots cultivated), plot characteristics (slope and size) and location (municipality, village size) as predictors of crop cultivated in a multinomial logit model. Results of this specification are presented in Appendix 3.

b. Potential mechanisms

Given that the relationship between crop cultivated and landslide cannot be explained by an endogenous allocation of crops on plots, I turn to the earth science literature to look for potential mechanisms. Both hydrogeology and agronomy study the phenomenon of erosion and the determinants of landslide occurrence and have developed a large literature on the topic (see Huggett 2007 for an introduction to the field of hydrogeology).

Rainfall is obviously an important driver of erosion, both for runoff erosion and landslide occurrence. However, a more important metrics is that of "useful water", defined by the difference between rainfall and evapotranspiration. A decrease in plant cover reduces evapotranspiration, thus increasing the quantity of useful water, holding rainfall constant. This increase in useful water directly worsens erosion through runoff or increases the probability of landslides through infiltration.

Systematic application of herbicide at multiple stages of the cropping season decreases plant cover and can trigger such a mechanism. Multiple studies have documented that specific weed management methods help alleviate erosion on slopes (Utomo & Senge 2002, Lenka, et al. 2017, Liu, et al. 2019). They recommend only partial weeding, as a good balance between benefits (less competition for the crops) and costs (increased erosion). These papers, however, only look at runoff erosion and, to the best of my knowledge, no study has examined the impact of weed management on landslide occurrence. Given that both phenomena have a lot in common, extending the results to landslides seems nonetheless reasonable.

The farm-level data collected for this paper does not contain information on glyphosate use during the past ten years. Given the fact that we collected recall data, it seemed highly unlikely that farmers would have remembered how much glyphosate they had used every single year on their crops. However, we do have detailed information regarding the current farming practices, including the amount of herbicide used for each cropping season over the past twelve months.

I can therefore show evidence that farmers use more glyphosate when planting GMO corn than with any other crop or corn variety. Like biotech corn, sige-sige is supposed to be resistant to glyphosate. However, this resistance is not as certain as GMO corn, and multiple informants have estimated that between 5 – 10% of the crop can be lost because of herbicide spraying. This claim, however, has never been confirmed scientifically as sige-sige corn has never been subject to any scientific research.

Table 3 shows the results obtained when regressing the amount of herbicide used per hectare on a series of crop dummies. In the region, chemical inputs are almost exclusively used on corn and rice, which is why I restrict my analysis to those two crops. Furthermore, given that non GM corn has almost entirely disappeared from the survey area and few farmers grow both rice and corn, the coefficients of the last two rows are estimated over very few observations and should be interpreted with caution. The difference between GMO, the omitted category, and Sige-sige corn is therefore the most relevant information. Column (1) shows that the amount of glyphosate used by sige-sige corn farmers is on average 1.65 litres lower than what is used by GMO corn farmers. This difference is sizable as it represents 38% of the mean. When controlling for village fixed effects and even household fixed effects, this difference remains significant, even though it decreases to 17.3% and 22.6% of the mean, respectively.

[INSERT TABLE 3 HERE]

The lower resistance to glyphosate of sige-sige corn certainly explains a large part of this difference. Credit constraints can also explain this result by limiting poor farmers – predominantly growing sige-sige corn – from buying as much herbicide as they wish.

A different root structure between GMO and sige-sige corn could also explain the correlation between variety grown and landslide occurrence. This would be the case, for example, if sige-sige corn had deeper roots than the biotech varieties. Unfortunately, I do not have any evidence to back up this claim. To date, neither the agricultural offices, nor the local university, have made any agronomic study of sige-sige corn and were not able to answer my question.

However, given that farmers replant sige-sige seeds saved at harvest, it is likely that they select those presenting specific traits that are more suited to the terrain they cultivate. If farmers believe that plants with deeper roots are more desirable, this process should therefore lead to sige-sige corn having deeper roots. To the contrary, biotech corn is developed by seed companies who may not have in mind the specific needs of the farmers cultivating steep lands but might focus on getting higher yields as well as pest and herbicide resistance.

c. Moderating effects and future trends

Slope gradient and extreme weather events are both obvious factors influencing the probability of landslides. In this section, I document how landslides are distributed across time, especially with respect to the two typhoons that hit the area during the past ten years. I then look at the relationship between crop variety and slope and how it has evolved over time. I finally bring those two factors together in a triple difference regression, estimating the moderating effects of both slope and typhoons.

Philippines has been described as the "most storm-exposed country on Earth" (Brown 2013). Every year, an average of twenty tropical cyclones enter its Area of Responsibility, nine of which actually cross the country (Cinco, et al. 2016). Figure 3 represents the trajectories of all recorded tropical storms in the Western Pacific region.

[INSERT FIGURE 3 HERE]

Most of these storms affect the northern island of Luzon while the island of Mindanao, situated off the typhoon path, is usually spared. Over the past ten years, two major storms have hit our study area: Washi in 2011 and Bopha in 2012, locally known as Sendong and Pablo, respectively. Each typhoon caused the deaths of over 1,000 people across the country. Their damage have been estimated at nearly 100 million USD for Washi and at over 1 billion USD for Bopha, which is considered as one of the most destructive storms in the history of the country (ESCAP/WMO 2012, OCHA 2013).

Typhoons are characterized by strong, sustained winds between 118 and 220 km/h and heavy rainfalls up to 2 inches/50mm per hour (NASA 2012). In Cagayan de Oro, Mindanao's second largest city, typhoon Washi brought more than a month's worth of rainfall within 24 hours, an extreme amount considering the wet tropical climate of the Philippines.

In the data, the passage of Washi and Bopha is clearly marked, with most of the reported landslides occurring during the years 2011 and 2012. Figure 4 shows the share of plots affected by a landslide during the past ten years. This share is equal to 21% on average during the typhoon years and drops to 2.5% on average during non-typhoon years.

[INSERT FIGURE 4 HERE]

In the survey, farmers had to report the slope of their plots using a series of pictures representing various angles, between 10% and 100% (respectively 5.7° and 45°). Only the pictures were shown to the respondents, not the corresponding gradient or angles. The pictures are reported in the Appendix 4. While the actual gradient of the slope is certainly prone to measurement error and should be used with caution, there is no reason why this measure should be biased in either direction or that the measurement error should be correlated with any variable of interest. No indication was given to the farmers as to whether they should state the slope of the steepest part of the plot, or the average slope. However, given that most plots are relatively small, with a median surface of 1 ha, there is little intra-plot slope variability. As an alternative measure of slope, farmers also had to report whether or not a buffalo could work on the plot. The correlation between both measures is – 0.47 and is strongly significant.

Table 4 presents the correlation between our two slope measures and the type of crop cultivated, controlling for year and village fixed effects. Both measures show a similar picture even though the results are less significant for the buffalo question. Columns (1) and (4) compare corn cultivation with other land uses and show that corn is, on average, planted on steeper plots. Column (2) breaks up between the three corn varieties and shows that biotech corn – the reference category – is planted on more gentle slopes than the other, less productive corn varieties. Given that a higher slope leads to more erosion, poorer soil and more strenuous labor, such a correlation is expected. However, when controlling for household fixed effect in column (3), the correlation disappears. This means that households who cultivate multiple crops and/or plots do not systematically choose what they plant according to the slope of the plot.

[INSERT TABLE 4 HERE]

This difference in slope between plots planted in biotech corn and those planted in other corn varieties reinforces the result discussed earlier that the higher incidence of landslides on GMO plots cannot be explained by the selection of plots. If anything, this selection effect should decrease landslide occurrence compared to other corn varieties.

The mediating impact of the slope on landslide occurrence is presented in Figure 5. The three graphs are constructed by regressing the landslide per hectare variable on a series of slope dummies. The reference category is the smallest slope of 10%.

The first graph shows that the probability of landslide increases linearly with the gradient of the plot and this relationship becomes statistically significant at a 30-percent gradient, which is in line with the literature on earth slumps (Highland & Bobrowsky 2008). The second graph presents the marginal effect of the slope on landslide in corn plots compared to other plots. A similar pattern emerges, even though less precisely estimated. This means that the steep slope increases the probability of landslide even more on plots planted in corn. The third graph presents the same relationship but comparing biotech corn with other corn varieties. This time, the differential effect of slope is negative and insignificant until the steepest slope category where it becomes positive statistically significant. For very steep slopes, GMO corn therefore appears to induce more landslides than other corn varieties.

[INSERT FIGURE 5 HERE]

To combine the effects of slope and extreme weather simultaneously, I run the triple interaction regression presented in Table 5. Due to the limited number of landslides on plots cultivated in non-GM corn and other crops, this analysis only compares biotech corn with sige-sige corn. Without this sample restriction, some of the coefficients would be estimated on less than ten observations and would not be informative.

Columns (1) and (2) are in line with the previous discussion on the relationship between slope, corn variety and landslides. Adding household fixed effects in column (3) does not fundamentally change the results but reduces the significance of the coefficients (p-value < 0.11 for slope and the interaction term). When typhoons are taken into account, in columns (4) – (6), the differential effect of slope between corn varieties remains very stable and only loses some significance. As expected, the slope of the plot during typhoon years is the most strongly correlated with landslide occurrence.

These results show that the physical characteristics of the plots combined with extreme weather events have the strongest influence on landslide occurrence. However, farming practices are also correlated with this hazard. For gentle slopes, biotech corn is associated with a lower incidence of landslides than sige-sige corn. When the slope becomes higher than 30-35 percent, the opposite becomes true. As discussed earlier, farming practices associated with each variety are likely to explain this difference as any physical difference between the plants has not been documented.

[INSERT TABLE 5 HERE]

5. Discussion

Two important points need to be addressed at this stage. First, can we infer any trend in the evolution of landslides for the future? Is this phenomenon likely to become more common? Second, what is the distribution of impacted farmers? Are specific categories more or less impacted by landslides?

a. Future trends in landslides determinants

First, the results presented above show that landslides are more frequent during typhoon years. Predicting future trends therefore requires to understand how these climatic events are likely to evolve as the climate changes over the century.

The impact of climate change on the frequency, intensity and path of cyclones is the subject of intense debate, summarized by the National Academy of Sciences (2016). The report states that

> *"Broad consensus has emerged as to the expected future trends and their levels of certainty (e.g., IPCC, 2013; Knutson et al., 2010; Walsh et al., 2015). Tropical cyclones are projected to become more intense as the climate warms. There is considerable confidence in this conclusion […] The global frequency of tropical cyclone formation is projected to decrease (Camargo et al., 2014; Knutson et al., 2008, 2010; Seneviratne et al., 2012; Walsh et al., 2015), but there is less confidence in this conclusion than in the increase in intensity; some credible models produce increases in frequency (Emanuel, 2013). The uncertainty is still greater in projections of tropical cyclone frequency in individual basins."*

How typhoon patterns will change over the island of Mindanao is therefore uncertain but, according to Knutson, et al. (2015), tropical storms occurrence might slightly decrease while typhoon occurrence (storms of at least category-4 intensity) should slightly increase. In this respect, the incidence of landslides in the mountainous regions of the island should also increase in the coming decades.

Another result from this paper is that biotech corn is associated with a higher occurrence of landslides when planted on steep slopes. Looking at the data, I find that the slope on which GMO corn is cultivated has increased over the past ten years. This trend is not present for other corn varieties (Figure 6). If this trend continues, then we should also expect an increase in the occurrence of landslides in the region.

[INSERT FIGURE 6 HERE]

Extending the area under cultivation could have a similar effect if the encroached land is steep or if it is cultivated using farming practices that increase the probability of landslides. Table 6 presents the marginal effect of encroachment on the crop planted using a multinomial logit regression. Encroachment is equal to one if the plot was cultivated for the first time after 2002 or if the farmer reported that this plot had never been farmed before he started cultivating GMO or sige-sige corn on it. 79 plots, or 12.5% of the sample, match one of these criteria. Results show that plots that have been encroached since biotech corn was authorized in the Philippines are 16 percentage points more likely to be planted in GMO corn and 14 percentage points less likely to be planted in open-pollinated varieties, controlling for village and year fixed effect.

[INSERT TABLE 6 HERE]

Encroached plots are also slightly steeper than other plots but the difference is not significant (p-value of two-sided test = 0.33).

The first three columns of Table 7 presents the results of a regression similar to Table 5 but investigating the mediating effects of encroachment instead of GMO corn. Land encroachment is not correlated with landslide occurrence in any way, on its own or through its interaction with slope or typhoon. Column (5) shows that planting GMO corn on encroached land does not significantly change the probability of landslides compared to non-encroached plots. Statistical power however becomes an issue given that both landslides and encroachment are not very common in the dataset.

On a national scale, the move away from biotech corn toward sige-sige seeds by a growing number of farmers in the Philippines, as documented in ISAAA (2017), could point toward a decrease in landslide incidence. Whereas in our area, sige-sige has been present for a long time and has mainly replaced open-pollinated varieties, its recent spread throughout the country has been at the expense of GMO varieties. However, the results of this paper do not imply that biotech corn in itself increases landslides occurrence. Rather, the most likely mechanism explored is through farming practices and input use, which are shaped – at least partially – by credit constraints. Additional work needs to be done in order to understand how farming practices change when farmers switch from GMO to counterfeit seeds. How expansion of MFIs in rural regions might help alleviate the credit constraints faced by the farmers also deserves to be better understood. Finally, looking at the evolution of slopes of the plots planted in biotech corn in the Philippines might give us a better understanding on potential future trends at the national level. Using several waves from the Census of Agriculture, I plan to tackle this research question in an extension of this paper.

[INSERT TABLE 7 HERE]

Predicting the net effect of those different factors would be highly speculative. If anything, we should not expect a dramatic increase or decrease in the number of landslides in the area but, as the climate changes and becomes more unstable, the uncertainty regarding environmental hazards is likely to increase. From a societal point of view, it is likely that a decrease in landslides resulting from a shift away from biotech to counterfeit seeds should be more than offset by the decrease in total production and the potential other environmental hazards induced by such seeds, at least in the short run. In the long run, however, the decrease in soil fertility induced by erosion can have disastrous impacts on the potential yields and affect the region's food security.

b. Distribution of landslide damage

Landslides are a frequent environmental hazard in the Upper Pulangi region. How this hazard affects different categories of farmers is an important and relevant policy question, especially given the high rate of poverty in the area.

Direct measures of wealth were only collected in 2018 and are potentially endogenous to both biotech corn cultivation and landslide occurrence. To investigate how farmers across the wealth distribution are differently affected by landslides, I use a pre-determined outcome, the area of land inherited, and a series of time-varying measures: area of land cultivated and owned, the number of plots cultivated and owned. Only the first measure is unequivocally exogenous but all yield similar results, as presented in Tables 8 and 9.

Columns (1) to (5) from Table 8 show that all measure of wealth are negatively associated with landslide occurrence per hectare. Poorer farmers are therefore relatively much more exposed to landslides than richer farmers. The next 5 columns use the area affected by the landslide divided by total plot area as the left-hand side variable and a similar pattern emerges: poorer farmers lose on average a significantly larger portion of their plots to landslides. Restricting the analysis to landslide episodes leads to similar results (not reported but available upon request).

[INSERT TABLES 8 AND 9 HERE]

Because landslides can remove a significant part of the top soil, farmers sometimes have to wait several years before replanting on the affected area. Table 9 looks at the correlation between wealth and the proportion of the plot that is unusable because of landslides. Once again, I find a negative and significant relationship for most wealth measures.

Digging deeper into the issue of unequal distribution of landslides across the wealth distribution, I replicate the analysis of tables 8 and 9 using a set of categorical explanatory variables. Figure 7 shows the coefficients obtained using land inherited, land owned and the number of plots owned as dependent variables. In all graphs, the omitted category is the dependent variable equal to zero.

[INSERT FIGURE 7 HERE]

The first set of graphs shows that households who inherited or owned less than 1.5 hectares of land face a similar risk or landslide per hectare. Over this amount, the probability decreases monotonically. A similar pattern is observed for the number of plots owned: households owning one plot do not face a different probability than those who do not own any land but households owning two plots of more have a smaller probability of being hit by a landslide.

The second and third sets of graph shows a similar picture for the share of land affected by the landslides and the share of land unusable because of landslides: most categories do not differ significantly from the base, except the top of the distribution which is less affected by landslides. For all three measures of landslide exposure, the coefficient of the last category of inherited or owned land is very similar to the mean of the dependent variable. For example, for households who inherited 6 hectares or more, the probability of landslide per hectare is 5 percentage points lower than for those who did not inherit anything. This effect is close to the overall probability landslide per hectare (4.8%) over the whole sample. This implies that wealthier households are much less exposed to landslides than the rest of the sample.

Figure 8 shows the distribution of inherited and owned land. Around a quarter of the households inherited more than 1.5 hectares and one third own more than 1.5 hectares. It is therefore the top quartile/tercile of the distribution that sees a decrease in the probability of being affected by a landslide. The effect on the share of land affected and share of land unusable, on the other hand, comes from the very top (96^{th} percentile) of the distribution.

[INSERT FIGURE 8 HERE]

Such a difference in the distribution of landslide occurrence is present both during typhoon year and non-typhoon years, as documented in Figure 9. This graph plots the mean predicted values obtained by regressing the probability of landslide per hectare on the interaction between typhoon years and the set of wealth dummies. All categories see a strong increase in the probability of being affected by a landslide during typhoon years, but households who inherited less 1.5 ha still face a much higher probability.

[INSERT FIGURE 9 HERE]

Landslides are therefore unevenly distributed among farmers, with the top of the wealth distribution experiencing relatively less damage. Note that our survey did not cover the very top of the distribution as we excluded households who owned more than 10 hectares of land. However, given that this region was cleared in the second half of the 20th century, it is not characterized by large estates dating back to the Spanish era. The few people controlling more than 20 hectares of land usually do not own them but are using them as part of a *prenda* (land-pawning) agreement. According to several informants in the region – including some of those big farmers themselves –, they only take prenda on valuable and productive land. As a result, they tend to control the best lands, i.e. those that are not steep and therefore less likely to be hit by a landslide. Omitting them from our analysis therefore does not change our results regarding the distribution of affected farmers.

6. Conclusion

The introduction of biotech corn has doubtlessly had positive impacts on the livelihoods of many farmers in the Philippines. However, the change in agricultural practices induced by those new varieties appear to have come at an environmental cost that has received very little attention in the literature.

Increased use of herbicide, leaving the soil less protected against heavy rains, and cultivation on steeper slopes over time both appear to drive this result. Even though this negative environmental impact appear relatively modest in the short run compared to the increase in yields and profits obtained through GMO cultivation, erosion can significantly decrease agricultural productivity in the long run. Addressing this issue is therefore important for policy makers if they do not want a productivity backlash in the coming decades.

Furthermore, the analysis of the landslides distribution shows that this environmental hazard affects mostly the poorer groups of the population (those who inherited or owned small amounts of land). This means that the people most exposed to this risk are those that are relatively the worst hit when a landslide happens. Several policy measures have already been put in place, such as free crop insurance and farmer's compensation during climatic disasters through a "calamity fund" but they remain poorly known by the poorest farmers. Only 10% of the farmers were covered by a crop insurance in 2018 despite free provision by the local governments. Improving this coverage could have a tremendous impact on the affected households but would require better information provision as well as a simplification in the application process.

Finally, regulatory authorities should take into account the potential impacts of new agricultural varieties on farming practices in when assessing them. When farmers change the type of seeds they plant, they can also change the type and mix of inputs they use and this whole system should be studied, rather than just the seeds themselves. Moreover, taking into account how such a system impacts different agro-ecological zones and take appropriate conservation measures is necessary to preserve agricultural productivity and food security in the most marginalized regions.

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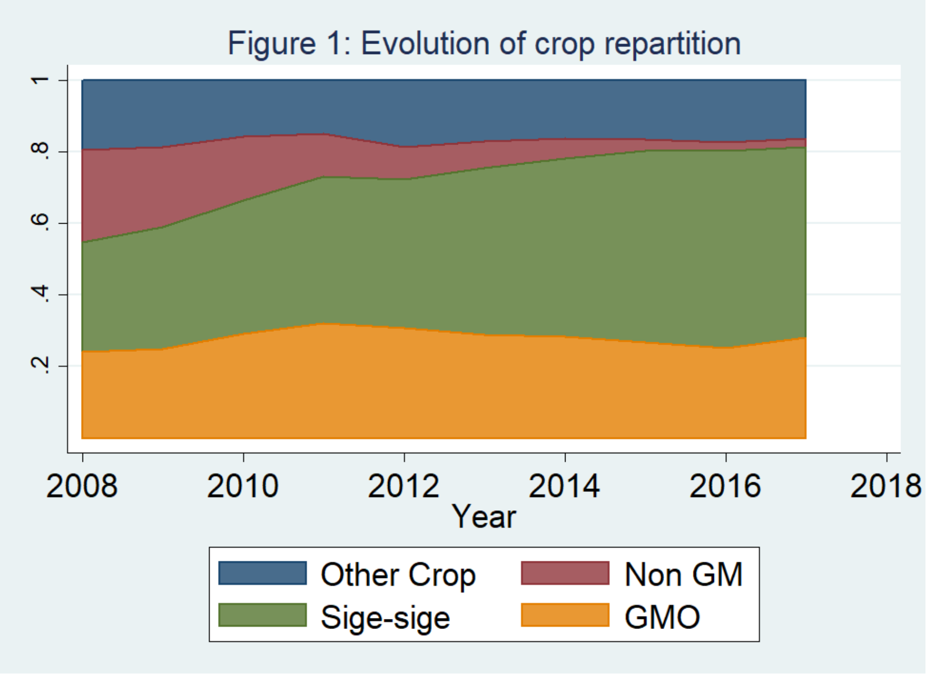
Figures and Tables



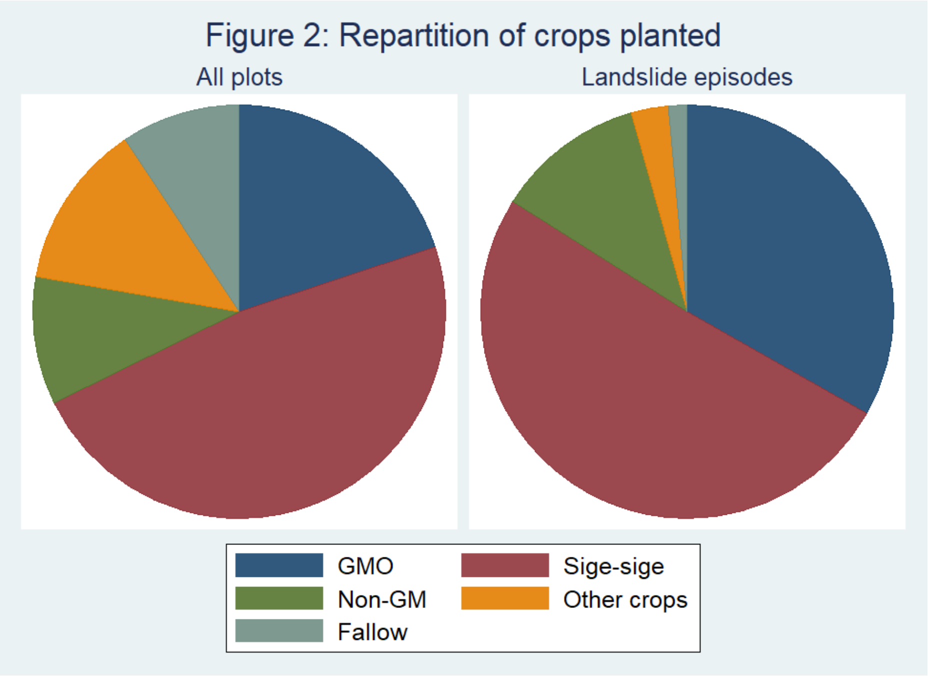
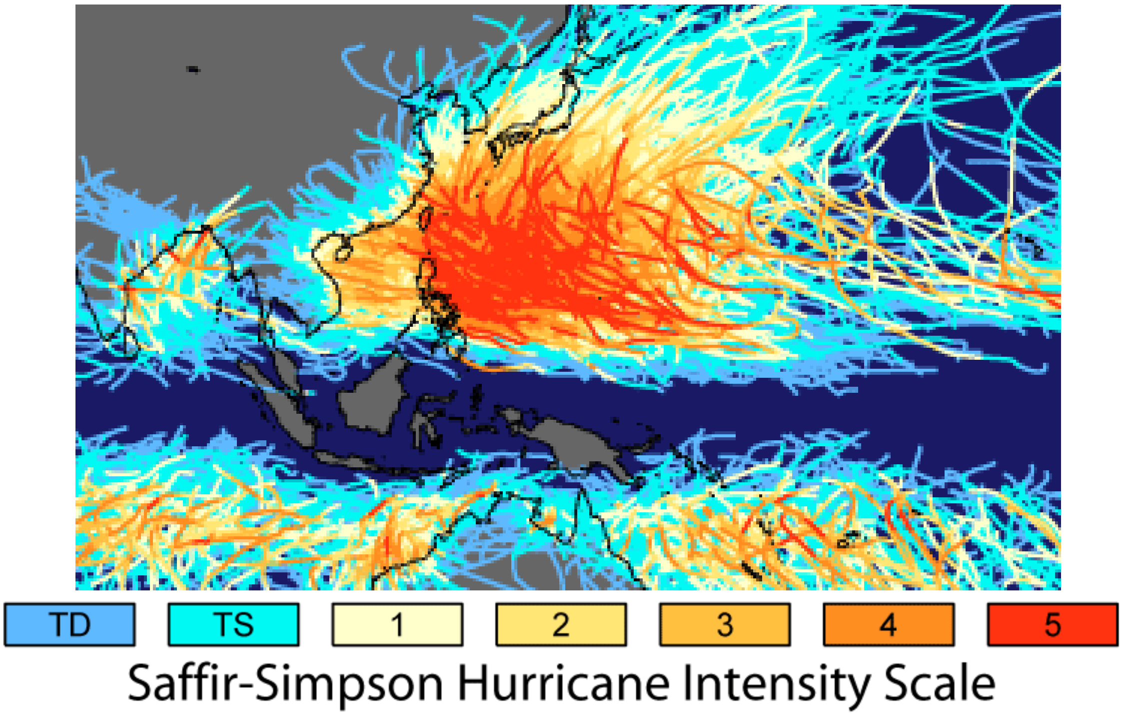


Figure 3 : Track and Intensity of all Tropical Storms



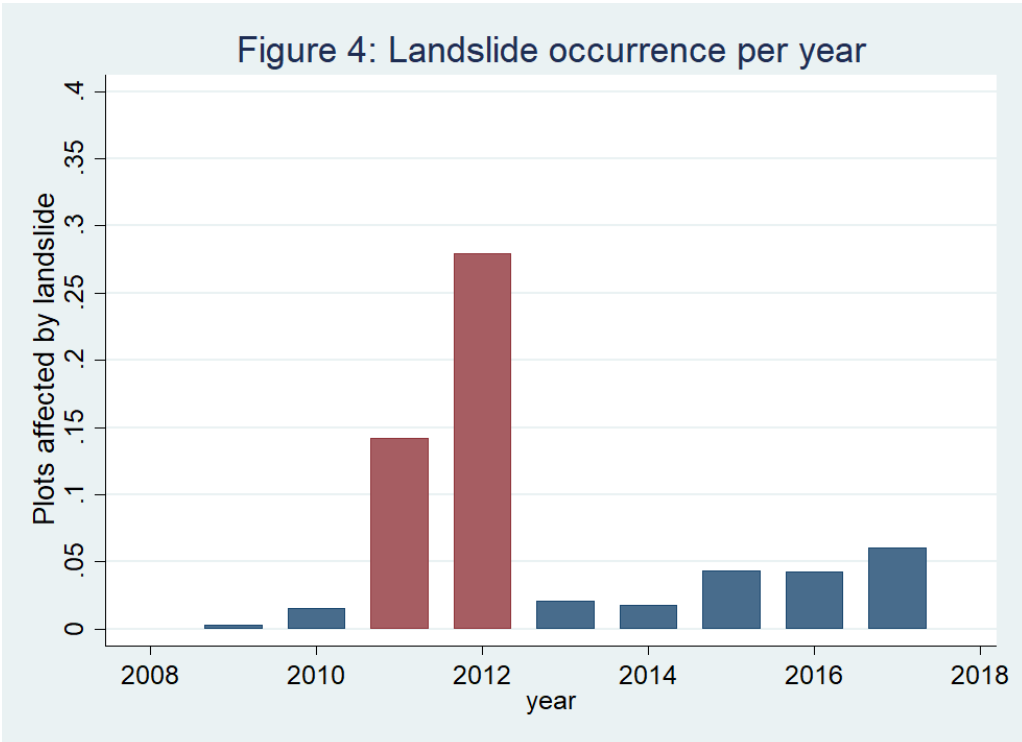


Figure 4: Landslide occurrence per year

Figure 5: Slope and landslide occurrence

90% confidence intervals displayed. Village and year fixed effects, standard errors clustered at household level

Figure 6: Slope over time

90% confidence intervals displayed. Standard errors clustered at household level

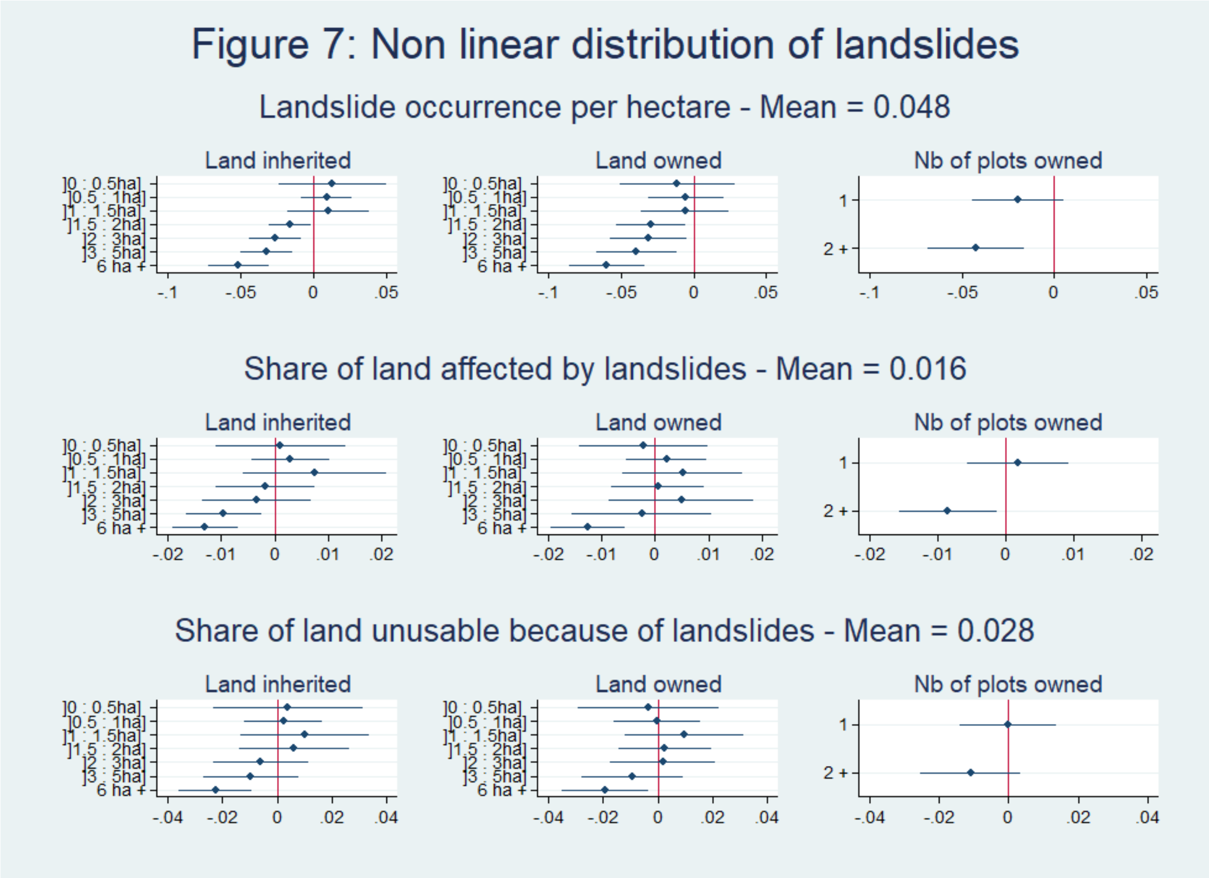


Figure 7: Non linear distribution of landslides
Landslide occurrence per hectare - Mean = 0.048
Land inherited
Land owned
Nb of plots owned
]0 : 0.5ha]
]0.5 : 1ha]
]1 : 1.5ha]
]1.5 : 2ha]
]2 : 3ha]
]3 : 5ha]
6 ha +
1
2 +
Share of land affected by landslides - Mean = 0.016
Share of land unusable because of landslides - Mean = 0.028

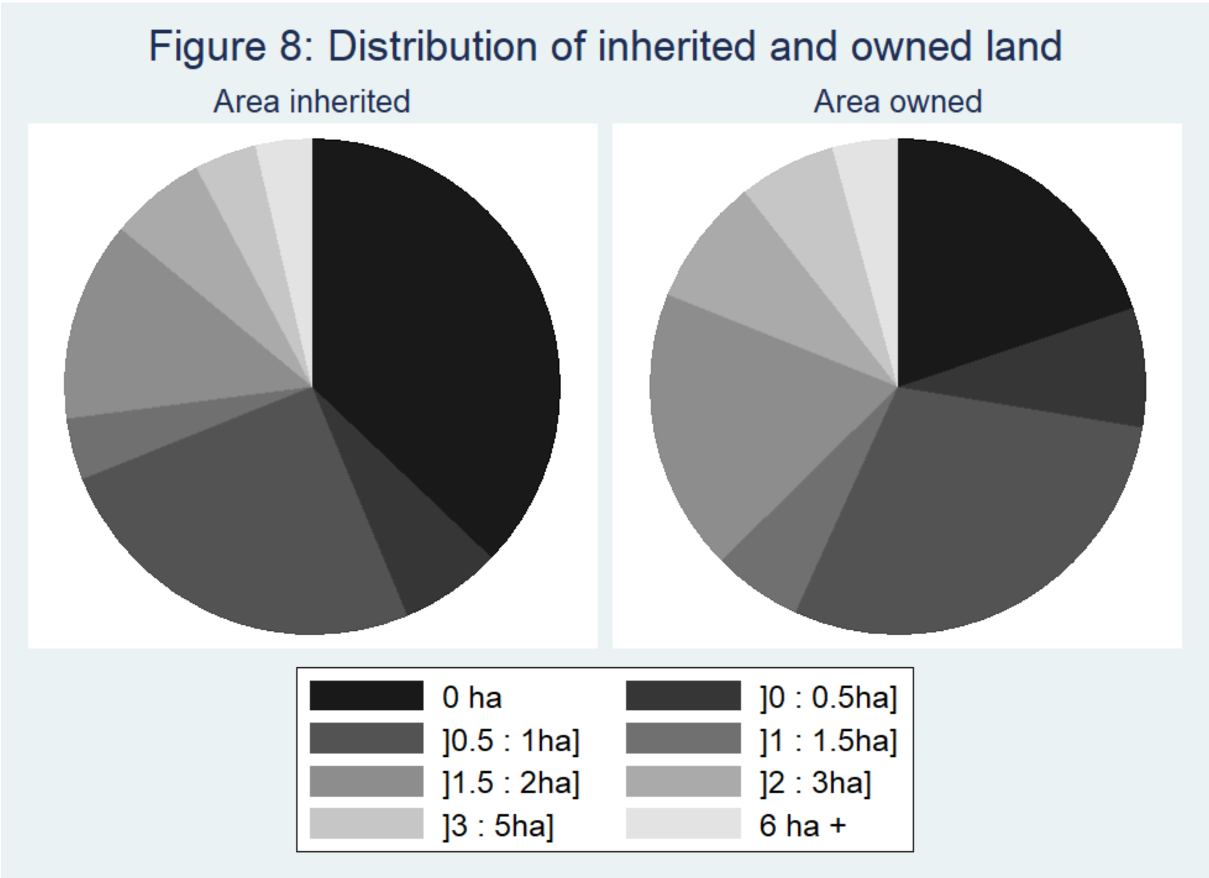


Figure 8: Distribution of inherited and owned land
Area inherited
Area owned
0 ha
]0 : 0.5ha]
]0.5 : 1ha]
]1 : 1.5ha]
]1.5 : 2ha]
]2 : 3ha]
]3 : 5ha]
6 ha +

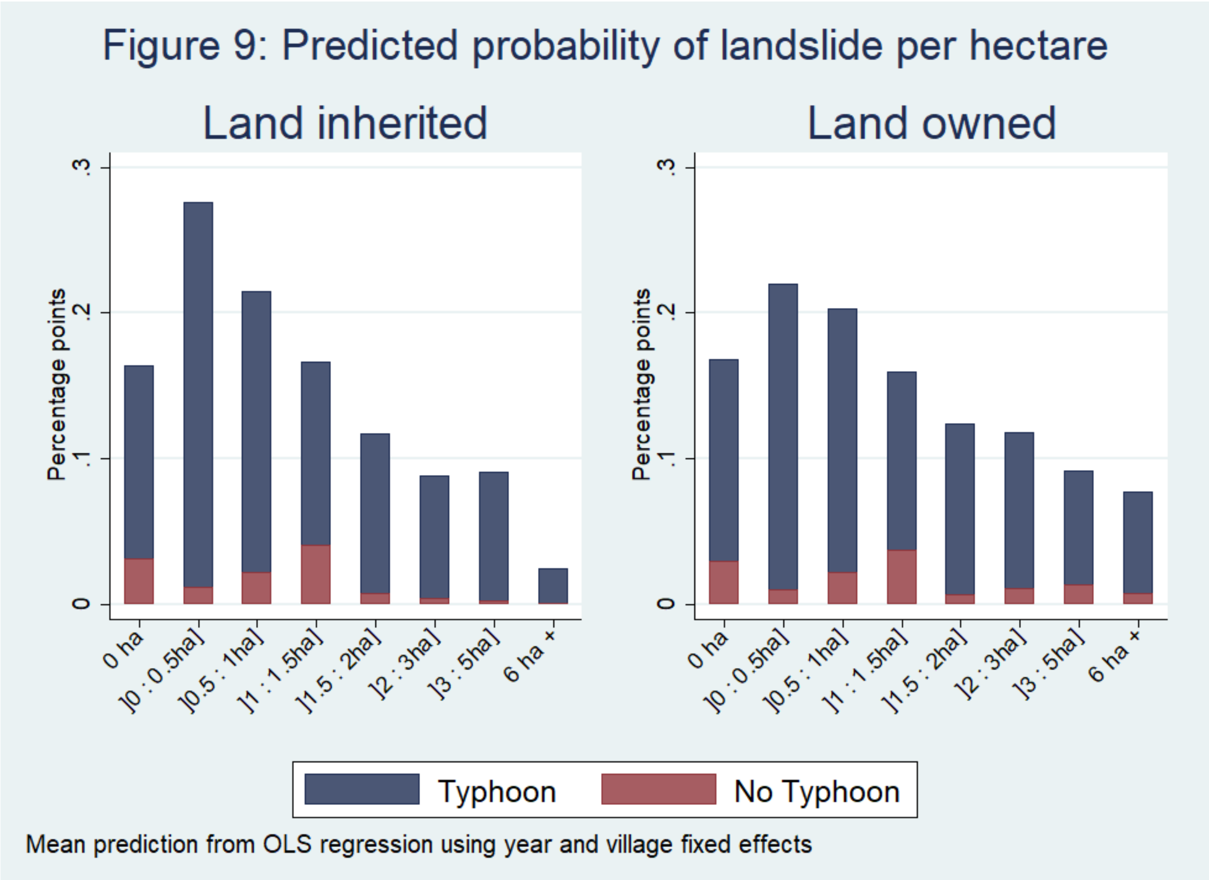


Figure 9: Predicted probability of landslide per hectare
Land inherited
Land owned
Percentage points
0
.1
.2
.3
0 ha
]0 : 0.5ha]
]0.5 : 1ha]
]1 : 1.5ha]
]1.5 : 2ha]
]2 : 3ha]
]3 : 5ha]
6 ha +
Typhoon
No Typhoon
Mean prediction from OLS regression using year and village fixed effects

Table 1A: Cross-section summary statistics

VARIABLES	(1) N	(2) mean	(3) sd
Plot size (ha)	631	1.581	1.346
Slope (percent)	595	0.450	0.300
Ever GMO	611	0.332	0.471
Ever Sige-sige	611	0.660	0.474
Ever landslide	611	0.358	0.480

Table 1B: Panel summary statistics

VARIABLES	(1) N	(2) mean	(3) sd
GMO corn	4,319	0.212	0.409
Sige-sige corn	4,319	0.483	0.500
non-GM corn	4,319	0.0998	0.300
Other crop	4,319	0.129	0.336
Plot fallow	4,319	0.0933	0.291
Landslide	4,319	0.0634	0.244
Landslide occurrence per hectare	4,319	0.0523	0.246
Landslide area (ha)	272	0.416	0.521
Unusable time after landslide	276	0.986	2.063
Nb of plots owned	3,582	1.012	0.677
Nb of plots used	3,582	1.231	0.544

Table 2: Landslide occurrence per hectare

VARIABLES	(1) All plots	(2) All plots	(3) All plots	(4) All plots	(5) All plots	(6) All plots	(7) Single plots	(8) Ever GMO	(9) Cult. before 2002
Corn	0.058***	0.047***	0.048***						
	(0.007)	(0.007)	(0.011)						
GMO corn				0.071***	0.069***	0.080***	0.095***	0.090***	0.095***
				(0.014)	(0.014)	(0.021)	(0.033)	(0.024)	(0.027)
Sige-sige corn				0.052***	0.040***	0.043***	0.043**	0.058**	0.041***
				(0.008)	(0.009)	(0.013)	(0.019)	(0.022)	(0.013)
Non GT corn				0.061***	0.054***	0.055***	0.046*	0.085**	0.056***
				(0.012)	(0.013)	(0.017)	(0.026)	(0.034)	(0.017)
Observations	4,319	4,303	4,274	4,319	4,303	4,274	2,358	1,525	2,089
R^2	0.090	0.202	0.230	0.093	0.204	0.232	0.218	0.238	0.231
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES
Village FE	YES	-	-	YES	-	-	-	-	-
HH FE	NO	YES	-	NO	YES	-	YES	YES	YES
Plot FE	NO	NO	YES	NO	NO	YES	NO	NO	NO

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Standard errors clustered at the household level

Table 3: Litres of glyphosate per ha

VARIABLES	(1) No FE	(2) Village FE	(3) HH FE
Sige-sige corn	-1.656***	-0.753**	-0.999*
	(0.330)	(0.327)	(0.576)
Non GM corn	-5.378***	-3.332***	-2.403
	(0.432)	(0.520)	(2.003)
Rice	-3.788***	-2.760***	-2.776***
	(0.634)	(0.533)	(1.059)
Observations	790	790	674
R^2	0.106	0.308	0.898
Village FE	NO	YES	-
Household FE	NO	NO	YES
Mean	4.340	4.340	4.422

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 4: Slope of the plot

VARIABLES	(1) Percent	(2) Percent	(3) Percent	(4) Buffalo use	(5) Buffalo use	(6) Buffalo use
Sige-sige corn		0.060*	0.010		-0.026	0.018
		(1.901)	(0.433)		(-0.588)	(0.697)
Non-GT corn		0.127***	0.022		-0.054	-0.013
		(2.723)	(0.652)		(-0.813)	(-0.306)
Other crop	-0.086**	-0.030	-0.044	0.087*	0.063	0.084
	(-2.173)	(-0.644)	(-1.119)	(1.762)	(1.069)	(1.559)
Fallow	-0.067	-0.013	-0.012	0.127***	0.104*	0.020
	(-1.614)	(-0.259)	(-0.355)	(3.144)	(1.954)	(0.540)
Observations	4,109	4,109	4,091	4,096	4,096	4,078
R^2	0.054	0.065	0.849	0.041	0.042	0.883
Year FE	YES	YES	YES	YES	YES	YES
Village FE	YES	YES	-	YES	YES	-
Household FE	NO	NO	YES	NO	NO	YES

Robust t-statistics in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 5: Mediating effects of slope and extreme weather on landslide occurrence

VARIABLES	(1) Landslide/ha	(2) Landslide/ha	(3) Landslide/ha	(4) Landslide/ha	(5) Landslide/ha	(6) Landslide/ha
GMO corn	-0.041*	-0.036	-0.002	-0.051**	-0.045*	-0.005
	(0.023)	(0.024)	(0.026)	(0.024)	(0.025)	(0.025)
Slope	0.037***	0.036***	0.050	0.007	0.006	0.023
	(0.012)	(0.013)	(0.031)	(0.011)	(0.011)	(0.030)
GMO*Slope	0.140**	0.134**	0.092	0.140*	0.134*	0.080
	(0.067)	(0.063)	(0.056)	(0.080)	(0.076)	(0.055)
GMO*Typhoon				0.063	0.059	0.049
				(0.080)	(0.080)	(0.081)
Slope*Typhoon				0.165***	0.166***	0.174***
				(0.061)	(0.060)	(0.061)
GMO*Slope*Typhoon				-0.030	-0.028	-0.014
				(0.157)	(0.156)	(0.158)
Observations	3,280	3,280	3,248	3,280	3,280	3,248
R^2	0.109	0.118	0.232	0.114	0.124	0.237
Year FE	YES	YES	YES	YES	YES	YES
Village FE	NO	YES	-	NO	YES	-
HH FE	NO	NO	YES	NO	NO	YES

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 6: Crop planted and encroachment

VARIABLES	(1) Average Marginal Effect
GMO corn	0.159***
	(0.034)
Sige-sige corn	0.076
	(0.061)
Non-GM corn	-0.142**
	(0.063)
Other crops	-0.061
	(0.048)
Fallow	-0.032
	(0.036)
Observations	4,319

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Year and Village FE

standard errors clustered at household level

Table 7: Mediating effect of encroachment

VARIABLES	(1) Landslide/ha	(2) Landslide/ha	(3) Landslide/ha	(4) Landslide/ha	(5) Landslide/ha
Encroachment	0.008	-0.016	-0.010	0.006	0.029
	(0.018)	(0.023)	(0.025)	(0.019)	(0.026)
Slope of the plot		0.068***	0.037*		
		(0.019)	(0.020)		
Encroach*Slope		0.051	0.044		
		(0.052)	(0.059)		
Encroach*Typhoon			-0.043		
			(0.090)		
Slope*Typhoon			0.161**		
			(0.076)		
Encroach*Slope*Typhoon			0.053		
			(0.144)		
GMO				0.019	0.031**
				(0.015)	(0.013)
Encroach*GMO					-0.061
					(0.039)
Observations	2,955	2,887	2,887	2,955	2,955
R^2	0.099	0.110	0.115	0.100	0.102
Year FE	YES	YES	YES	YES	YES
Village FE	YES	YES	YES	YES	YES

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table 8: Landslides and wealth

VARIABLES	(1) Occurrence	(2) Occurrence	(3) Occurrence	(4) Occurrence	(5) Occurrence	(6) Damage	(7) Damage	(8) Damage	(9) Damage	(10) Damage
Inherited area	-0.008***					-0.002***				
	(0.001)					(0.000)				
Owned area		-0.008***					-0.001*			
		(0.002)					(0.001)			
Cultivated area			-0.015***					-0.005***		
			(0.003)					(0.001)		
Nb of plots owned				-0.018***					-0.004**	
				(0.005)					(0.002)	
Nb of plots cultivated					-0.011**					0.000
					(0.005)					(0.003)
Observations	3,473	3,482	3,482	3,482	3,482	3,510	3,519	3,519	3,519	3,519
R^2	0.100	0.101	0.104	0.099	0.097	0.087	0.086	0.091	0.086	0.085
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Village FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Table 9: Share of land unusable and wealth

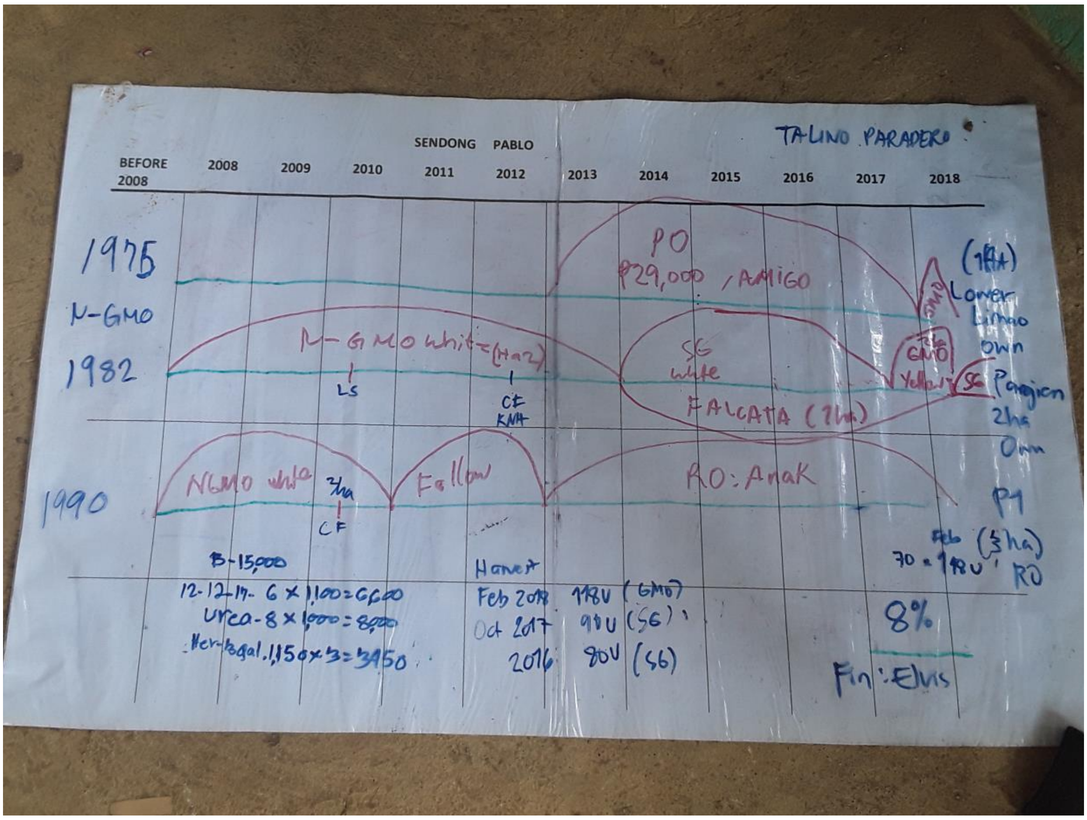
VARIABLES	(1) Unusable	(2) Unusable	(3) Unusable	(4) Unusable	(5) Unusable
Inherited area	-0.002**				
	(0.001)				
Owned area		-0.002			
		(0.001)			
Cultivated area			-0.008***		
			(0.002)		
Nb of plots owned				-0.005*	
				(0.003)	
Nb of plots cultivated					-0.002
					(0.004)
Observations	3,510	3,519	3,519	3,519	3,519
R^2	0.072	0.071	0.080	0.071	0.070
Year FE	YES	YES	YES	YES	YES
Village FE	YES	YES	YES	YES	YES

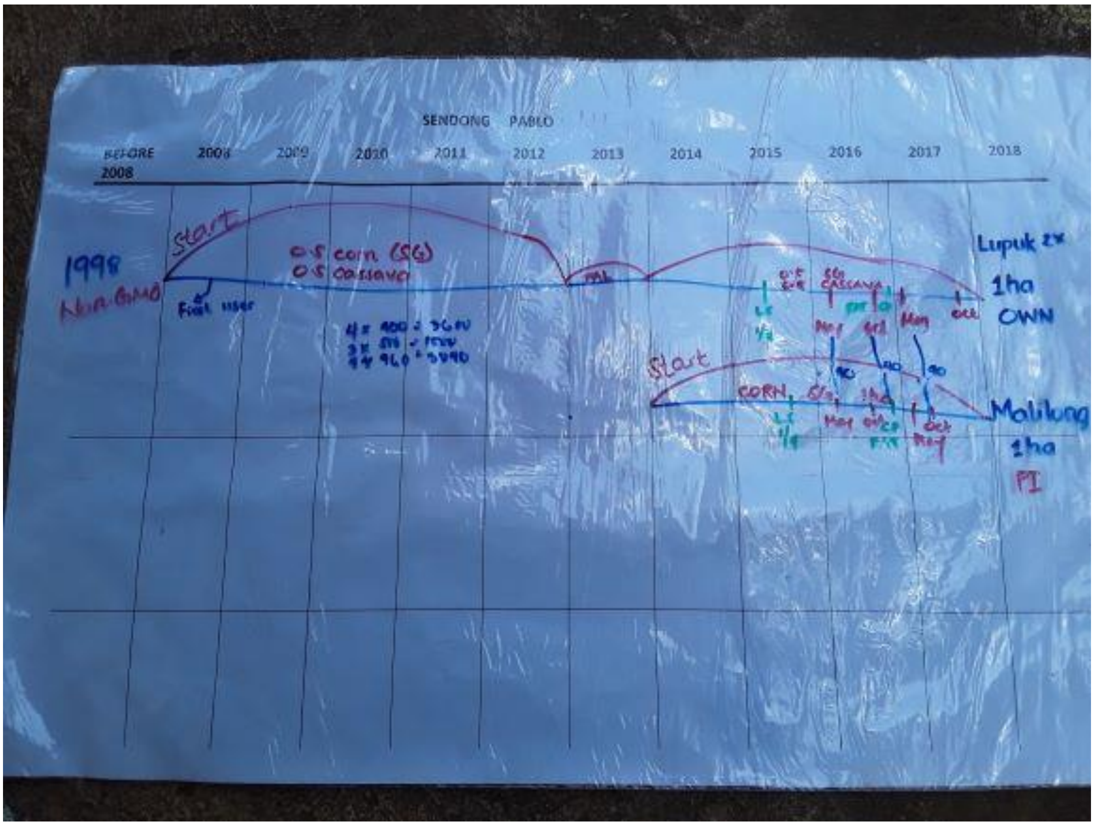
Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Appendix

Appendix 1 – Photographs of earth slumps

Appendix 2 – Timelines





Appendix 3 – Inverse-probability weighting matching

Crop and landslide: Inverse-Probability Weighting Matching

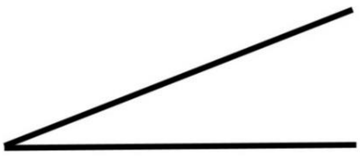
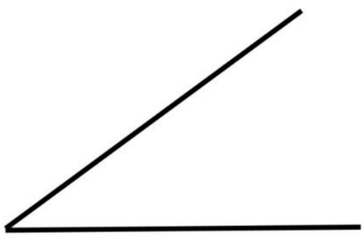
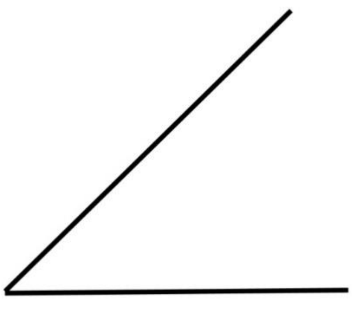
	(1)	(2)
VARIABLES	ATE	Potential Outcome Means
Sige-sige vs. GMO	-0.032*	
	(0.019)	
Non GM vs. GMO	-0.042**	
	(0.020)	
Other crop vs. GMO	-0.070***	
	(0.020)	
Fallow vs. GMO	-0.073***	
	(0.019)	
GMO corn		0.085***
		(0.018)
Observations	4,047	4,047

Robust standard errors in parentheses

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Variables used for inverse-probability weighting matching: household head's age years of education, ethnicity, number of plots cultivated by the household, slope and size of the plot, municipality and village size dummy.

Appendix 4 – Pictures used for slope measurement

10%	
20%	
30%	
40%	
75%	
100%	

Note: Gradients were not shown to respondents.