Volcanic Hazards, Land and Labour

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Abstract

We study the behavior of farmers living under the threat of the Tungurahua Volcano in Ecuador. Recent eruptions have caused significant losses, including loss of crops, death of livestock, and dwelling destruction. We collected a unique data set after a major eruption in 2016. We interviewed 222 farmers in the risky zone and 260 in a nearby control zone to understand why farmers choose to remain in the risky zone despite the existence of public programs aimed at relocating them in safe zones. We examine land and labor, which are farmers' main productive assets. Firstly, we investigate the capitalization of volcanic hazards in farmland values and find a negative price premium of 21% compared to the control zone. Secondly, we explore nonfarm labor in response to volcanic risk. Finally, we argue that repeated ashfall events increase the illiquidity of farm households' assets such as farmland and that agricultural human capital is difficult to convert into non-agricultural one. Our results convey important information for public policies aimed at supporting adaptation and resilience of people living under the threat of volcanoes.

Highlights

- Farm households remain in volcanic areas despite repeated loss of crops and livestock.
- We analyze the case of the Tungurahua Volcano in Ecuador using primary data.
- We investigate the role that productive assets, i.e. land and labor, play in the decision to remain in the risky zone.
- We show the significance of integrated land and labor policies to address natural hazards.

Keywords

Ecuador; Volcano; Shock; Agriculture; Farmland; Labor

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Q15; D81; Q54

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1. Introduction

Natural disasters increasingly affect livelihoods, which translates into significant research efforts and financial resources devoted to risk mitigation, adaptation and resilience policies. Among those disasters, volcanic activity is classified as a geophysical natural disaster that is “a hazard originating from solid earth”, with four potential outcomes, i.e. ash fall, lahar, pyroclastic flow and lahar flow. There has been 242 volcanic events between 1900 and 2017 around the world, causing 96,366 deaths and more than 6.6 million affected (Emergency Events Database[1]), as well as a wide range of economic, social, and psychological impacts (Doocy et al., 2013; Glaser, 1996; Wilson et al., 2011). Volcanic disasters also have dramatic impacts on agriculture, as eruptions and ashfalls degrade farmland and vegetation, and cause severe livestock and crop losses. Nevertheless, in the long-term ashes can favor agricultural land quality, as they provide nutrients for the soil (Cook et al., 1981; Kelman and Mather, 2008; Wilson et al., 2011), which constitutes an incentive to farm under the threat of volcanoes.

Ecuador is particularly affected by volcanic hazards. According to the EM-DAT, between 1975 and 2017, Ecuador was affected by 12 episodes of volcanic activity, affecting a total of 1,479,426 people.[2] The Tungurahua, 5,023 m, located in the central Andean region in the Tungurahua province, is the most active volcano in the country. After a long period of quiescence of nearly 80 years, the Tungurahua initiated continued but various eruptive activities in 1999, from violent explosions with pyroclastic flows and tephra falls to minor eruptions with ash emissions (Le Pennec et al., 2012). These geological hazards have produced large private economic losses as well as severe damages to physical infrastructure such as road, water systems and electricity, schools, health centres and official building that caused a repeated drain on public resources. As a result, disaster management policy has evolved from ad hoc solutions to long term and nationwide disaster management policy (Solberg et al., 2003). Among the new policy instruments implemented by the Ecuadorian government there is the building of a community-based network of volunteers known as vigías, early warning system for civil protection and evacuation (Armijos et al., 2017; Stone et al., 2014), public awareness campaigns, and, above all, there is the construction of houses in resettlement zones. Public authorities hoped that relocating households from exposed areas to safe areas would help mitigating volcanic risk.

Despite the existence of relocation programs, recent research has stressed that some populations living under the threat of the Tungurahua do not want to be relocated to safe areas (Armijos and Few, 2015). Some families have definitively resettled in these zones while continuing to cultivate their land on the slopes of the volcano, whereas other people stayed at their initial dwellings in the communities affected by ash falls. This phenomenon is not specific to Ecuador, and often occurs in other areas of the world threatened by volcanic hazards (Gaillard, 2008; Lavigne et al., 2008; Wilson et al., 2007).

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[1] EM-DAT: The Emergency Events Database - Université catholique de Louvain (UCL) - CRED, D. Guha-Sapir - www.emdat.be, Brussels, Belgium

[2] “In EM-DAT, it is the sum of the injured, affected and left homeless after a disaster”. “Affected: People requiring immediate assistance during an emergency situation. The indicator affected is often reported and is widely used by different actors to convey the extent, impact, or severity of a disaster in non-spatial terms. The ambiguity in the definitions and the different criteria and methods of estimation produce vastly different numbers, which are rarely comparable” (http://www.emdat.be/guidelines).

The literature has emphasized both hazard-related and non-hazard related factors that shape people's behavior in facing volcanic hazard, i.e. risk perception, and cultural, social and economic factors. Risk perception has attracted the widest range of studies. A good overview can be found in the special issue of Journal of Volcanology and Geothermal Research 2008 (See also Van Manen, 2014; Rodrigez-Vangort, 2015). Cultural beliefs and social values have been studied by sociologists, anthropologists and geographers (Armijos et al., 2017; Few et al., 2017; Tobin and Whiteford, 2002). Evidence from case studies suggests that populations tend to stay in volcanic areas for the following reasons: lack of knowledge of volcanic hazards, marginal status of populations living in risky zones, volcanoes as a vector of cultural identity, volcanoes as "actors of change" (Bachri et al., 2015; Gaillard, 2008). Economic studies usually focus on risk and time preferences (e.g. Bchir and Willinger, 2013; Willinger et al., 2013).

This paper aims to contribute to the literature by investigating the extent to which farm households' productive assets, land and labor, play in the decision to remain in the risky zone. Despite their importance in households' coping strategies under shocks (Dercon, 1998; Ellis, 1998; Rose, 2001), they have received little attention in the literature on volcanic risk. After repeated ash fall events, a portfolio position in these becomes at least temporarily irreversible. The land may become hard to trade when desired or sold at a discount price. Agricultural human capital and skills have a farm-specific component, knowledge is experientially obtained and thus may not be easily transferable to other places. In addition, occupational mobility is limited by workers abilities and geographical mobility constraints. Farmers are thus trapped in a portfolio that they cannot exit. Meanwhile, land remains a strategic asset that provides the basis for rural livelihoods whereas labor skills match the needs required by agricultural tasks. This leaves little option other than to "rationally choose" to live with volcanic risk.

To address the research question, we conducted a field survey allowing us to collect detailed information on farmers' livelihoods in volcanic areas of Ecuador. However, the relevance of our analysis goes beyond the specific context of Tungurahua and applies to a wide range of natural hazards. Our results also convey important information for public policies aimed at supporting adaptation and resilience of people living under the threat of natural disasters.

The rest of the paper is organized as follows. Section 2 discusses the literature on farm households' coping responses under shocks in order to lay the foundations for the succeeding sections. Section 3 provides information on the study area. Section 4 explores the land and labor characteristics that can shed light on why farm households stay in the risky zone despite volcanic threat and policy that explicitly encourage migration out of this area, while section 5 concludes with some policy recommendations.

2. Farm households' coping responses under shocks

Farm households are an emblematic case of the dilemmas faced by populations living on the threat of volcanoes: on the one hand, ash falls often destroy (or decrease) their productive capital, i.e. land and labor; and on the other hand, volcanic activities can increase farmland quality in the long run. The economic literature on farm households' consumption smoothing, asset accumulation and coping strategies under shocks is prolific (Carter and Barrett, 2006; Dercon, 1998; Ellis, 1998; Hoddinott, 2006; Kochar, 1999; Reardon and Vosti, 1995; Rose, 2001; Rosenzweig and Wolpin, 1993; Rosenzweig and Binswanger, 1993; Zimmerman and Carter, 2003). It lays down the foundations on farm households' behaviour in their consumption, production and risk-response strategies, with a focus on their accumulation and use of productive and non-productive assets, and on their labour allocation decisions between farm labour and nonfarm labour.

Farm households put in place various self-insurance strategies to cope with risks to their livelihoods (Corbett, 1988). The imperfection or inexistence of credit and insurance markets affect households' decision-making (Rosenzweig and Wolpin, 1993). Income shocks can lead farm households to decrease their consumption, health and education expenses which has an impact on their long-term welfare through lower nutrition, human capital and long run consumption (Carter and Barrett, 2006; Corbett, 1988; Jensen, 2000). Savings may also be used to smooth consumption (Udry, 1995). Likewise, management of assets is central, such as livestock used as buffer stock against income shocks (Fafchamps et al., 1998; Rosenzweig and Wolpin, 1993). Households also carry-out trade-offs between productive and non-productive assets, as well as liquid assets and illiquid asset accumulation (Dercon, 1998). Households' members may also supply labor into the nonfarm labor market in order to cope with risk in farm production (Fafchamps, 1993; Kochar, 1999; Rose, 2001).

The pattern of farmers' response to shocks will also depend on their risk preferences.[3] If they are risk-neutral, it is expected that they will devote more time to activities leading to higher expected marginal return (Mishra and Goodwin, 1997). If they are risk averse, they would tend to allocate less labor resources to the risky occupation (that is farming in the risky zone) and more labor resources in labor in safe zones (nonfarm).

Coping strategies speak to the notions of vulnerability, resilience and risk assessment. Individual behaviors in presence of natural hazards must thus be approached in the light of these concepts. There are various types of vulnerability: households' vulnerability to the risk of not being able to meet their basic needs, such as access to food, housing and health services; vulnerability to the risk of falling into poverty (non-poor households who experience a shock and fall into poverty); and vulnerability of poor households to permanently staying in poverty (i.e. chronic poverty) and becoming caught in a poverty trap, with limited resilience. Whatever the approaches of vulnerability, these approaches overlap in three ways: the degree of risk (probability) for a household to be exposed to a volcanic shock; the magnitude of the shock; and the household's ability to respond to these shocks and return to its initial position (resilience). The latter depends on their asset endowments and the liquidity of these assets.

[3] See Binswanger (1980), Brunette et al. (2015), and Holt and Laury (2002) for discussions on farmers' risk preferences measured through revealed preference and stated preference methods.

3. Presentation of the study area and sample

3.1. Study area

The Tungurahua is one of the Ecuadorian volcanoes that entered an eruptive phase in 1999 (after nearly one century quiet period) and has been active on many occasions. Main eruptions occurred in 2006, 2008 and 2010 but ongoing volcanic activity has been observed since 1999. More than 30,000 people live under the direct threat of the Tungurahua, and more than 200,000 live under the threat of sporadic ash falls (Armijos and Few, 2015). The main economic damages and losses associated to Tungurahua eruptions, even those of minor importance, result from ash and tephra falls that destroy crops and natural pastures, impact the roofs and the glazes of houses, kill animals, cause respiratory diseases for both humans and animals. Since most people in the affected communities are heavily dependent on agriculture for their livelihood, eruptions translate into significant income loss, food vulnerability, and for the poorest, enormous difficulties to recover. Resilience to volcanic activity is thus key for the affected populations.

Our sample of households is located in three provinces of Ecuador, Tungurahua and Chimborazo, which surround the Tungurahua volcano for the affected zone and Morona Santiago for the control zone. The affected area was chosen using the map of eruptive deposits (see figure 1). The choice of the control zone was based on the similarity in agro-climatic conditions, using several sources of data capturing topography, climate and other geographical characteristics including altitude, slope, theoretical sunning, azimuth and distance from the village center to the nearest main road.[4] We began with the calculation of the mean value of each criterion for the two villages Puela and Bilbao[5] within a circle of one kilometer. For each criterion, a band has been defined with limits defined by the average +/- one standard deviation. Similar zones have been searched in the whole country so that the average of each criterion in a circle of one kilometer falls into the band defined for the affected zone. Among all the possible areas which emerged from this exercise, we chose those which were the closest to the affected area, i.e. the parish Quimiag located in the province Morona Santiago.

We conducted a quantitative survey in August 2016 in both zones four months after the eruption of March 2016. A total of 489 farm households were randomly selected by random walk, 222 in the risky zone and 260 in the control zone.[6] Data were collected from households' heads. The objective was to establish a snapshot of inhabitants' response to volcanic activity. Many issues such as risk exposure and perception, risk coping, agricultural land values, residential location choice have been addressed. We collected a large amount of plot-specific information on soil quality, slope, location and accessibility as well as agricultural use. Finally,

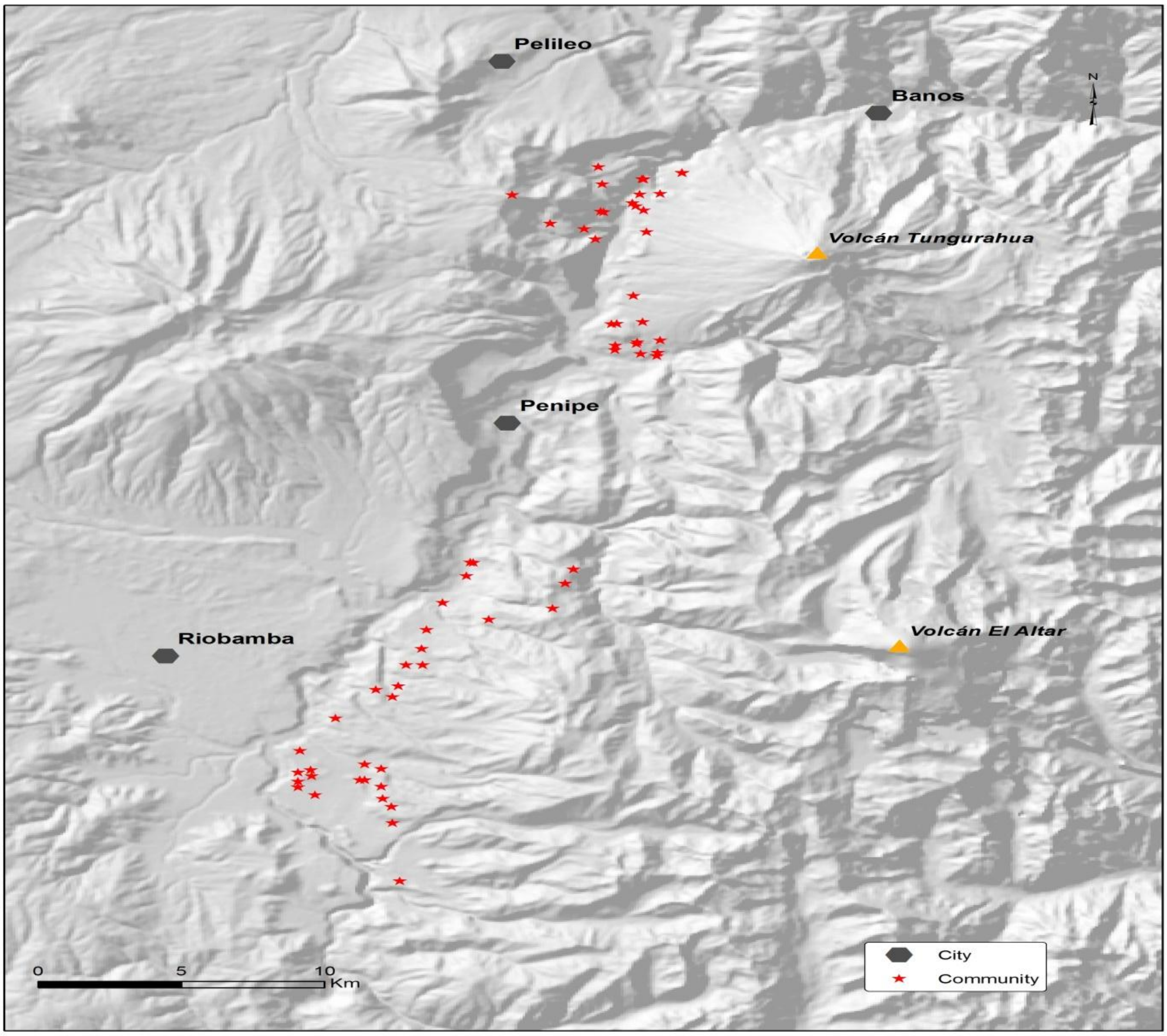
[4] Theoretical sunning is calculated as a function of the orientation of the slopes. The azimuth is the angle between the direction of a place and the geographic North. The source of the altitude data is the Shuttle Radar Topography Mission (SRTM) with an accuracy of 90m in Jarvis et al. (2008) International Centre for Tropical Agriculture (CIAT), available from http://srtm.csi.cgiar.org. The slope, azimuth and the theoretical sunshine are derived from the altitude and calculated with ArcGIS10 (Spatial Analyst module). The main roads are extracted from the Open Street Map database: http://www.openstreetmap.org.

[5] The values are: slope: 9.72 – 25.66 %; altitude: 2396 - 2845 m; sunning: 1 738 857 - 1 794 563 W.m-2.s ; azimuth: 121 - 274 ° ; distance to main road: 6573 - 12859 m.

[6] The target population has been defined as farm households, i.e. households that operate a holding regardless the residential choice. According to the 2010 Census, a total of 854 households including 2670 members were living in the three parishes located in the most affected zone. In the parish of the control zone, the census indicates 1480 households and 5257 individuals.

we collected socio-demographic characteristics of households' members as well as their employment status.

Figure 1 : Location of communities



3.2. Household socio-economic characteristics

Land is the first key asset in agriculture. Table 1 gives some information about land tenure, land size and type of activity. In both the risky and control zones, most respondents own farmland: respectively 75.4% and 78.6% of the plots for which we have characteristics are owned by farmers belonging to our sample. As a result, renting land is not extensive: 16.4% of plots in the risky zone and 18.5% in the control zone. Contractual arrangements are divided into equal parts for cash rent and sharecropping. Land is often rented on a short-term basis. Approximatively 50% of contracts last less of one year. However, nearly one third of contracts have an indefinite term. Formal property rights through titling have been secured for a vast majority of parcels (83%).

Table 1. Household socio-demographic characteristics

Description	Risky zone	Resettlement zone	Control zone	All sample
Tenure				
Percentage of owned plots	75.4		78.6	77.1
Percentage of usufruct plots	8.2***		2.8	5.3
Percentage of plots with formal property rights	83.2		81.7	82.4
Percentage of rented plots	16.4		18.6	17.6
N= total number of plots	341		393	734
Contractual arrangements				
Percentage of rented plots under cash rent	46.8		52.6	50.0
Percentage of rented plots under short term contracts	55.1		58.0	56.6
Percentage of rented plots with indefinite term	33.3		28.4	30.8
N= total number of rented plots	56		73	129
Landholding size				
Mean holding size (ha)	1.46**		0.71	1.06
N= total number of plots	341		393	734
Plot activity				
Percentage of plots allocated to agriculture	74.9***		45.2	59.0
Percentage of plots allocated to livestock	11***		36.5	24.7
Percentage of plots allocated to maize cultivation	69.7***		41.5	57.0
Percentage of plots allocated to potato cultivation	2.1		17.9	9.1
N= total number of plots	341		393	734
Labor				
Average age of household head	54.5	57.1**	52.7	54.1
Percentage of working men among total members of the household	58.1**	57.2**	48.9	52.6
Average age of household working members	44.8**	45.9***	41.7	43.3

Household working members educational attainment				
Percentage of working member without education	6.5***	5.6***	10.6	8.7
Percentage of working member with primary education	64.9***	65.1***	48.9	55.8
Percentage of working member with secondary education	22.6***	24.2***	33.7	29.3
Percentage of working member with superior education	6.0	5.2	6.8	6.3
N = total number of working members	248	270	696	1214
Non productive assets per household				
Number of rooms in the home	2.81 (***)	3.35**	2.93	3.0
Number of television sets that are working	0.74 *(*)	0.89	0.98	0.90
Number of radios that are working	0.69**	0.77	0.80	0.77
Number of washing machines operating	0.22***	0.19***	0.08	0.13
Number of refrigerators operating	0.46	0.53	0.55	0.52
Number of bycicles	0.10***	0.18	0.24	0.10
Number of motorcycles	0.09	0.13**	0.06	0.08
Number of DVD players	0.23*	0.27	0.36	0.31
Number of stereo systems	0.11***(**)	0.23	0.25	0.21
Number of computers	0.13	0.14	0.16	0.15
Number of vehicles	0.19** (**)	0.27	0.26	0.24
N=total number of households	111	111	260	482

*** p<0.01, ** p<0.05, * p<0.1 indicate if the difference between the risky/resettlement zones and the control are statistically significant. Stars in bracket refer to the difference between the risky and resettlement zone.

The landholding size is very small in the areas considered: 47.9% of households cultivate less than one hectare and the mean landholding size is 1.5 hectares. In addition, farmland distribution is highly unequal: farms with less than one hectare cultivate only 6.8% of the total land whereas farms with more than 5 hectares, which represent 8.7% of farms, occupy 56.2% of total land.

The evidence is mixed as to the degree of specialization of farmers. In the risky zone they allocate most of their plots to agriculture (74.7%) whereas farmers in the control zone choose a mixed farming system in which 58.6% are allocated to crops and 24.6% to pasture and livestock, the remaining land being in fallow. Maize is the main crop cultivated on agricultural land in both zones. Potato is the second crop in the control zone whereas bean is in the risky zone.

Family labor is the second key asset in agriculture. Since the family labor force depends on the personal characteristics of household members, the relevant parameters are family size, age and sex composition of the household labor force, and human capital accumulation. Table 1 gives an overview of the main households' members characteristics. On the whole, households in risky, resettlement and control zones are relatively homogenous in terms of age and gender. There are slightly more men in the risky zone where they represent 51.8% of the risky zone population and in the resettlement zone (52.2% of the resettlement zone population) than in the control zone where men account for 47.3% of the control zone population. The population is relatively younger in the control zone where the average age is 34 years than in the risky (34.6 years) and resettlement zone (37.6 years). This also holds true for the household head. As far as human capital is concerned, level of schooling of members who are economically active is low. If we consider the whole sample, nearly 8.7% of workers never attended school or attended just kindergarten and 55.8% completed primary school. Only 29.3% of the workers completed secondary school and 6.3% have completed a university cycle. In both risky and resettlement zones, most workers completed a primary school whereas workers in the control zone tend to have completed more years of education. Since education is essential for improving individual employment prospects, this low educational attainment may prevent people to look for distant jobs or to engage in local nonfarm income generating activities.

Non-productive assets consist mainly in dwellings, durable (electronic) goods and vehicles. If we proxy wealth by non-productive asset ownership indicators, we obtain similar relative pattern. On the whole, households in the risky zone hold significantly less durable goods than households in the resettlement zone and the control zone.

3.3. Exposure and responses to volcanic shocks

Among the 222 farmers living in the risky zone, 56% experienced damaged dwelling following the eruption of March 2016, such as damaged roof, walls, windows, and interior furniture. 57% had a total loss of their crops and 32% a partial loss. 46% experienced livestock loss. They implemented several coping strategies as shown in Table 2. When facing a shock, households are expected to implement insurance mechanisms, dispose of productive assets, borrow money from friends, relatives, a bank or cooperative, and reduce their consumption levels (Corbett, 1988). They tend to first protect income generating assets, even at the detriment of current consumption; with productive assets sold or abandoned as a last resort (Ellis, 1998). In our study area, farmers behaved as expected[7] with two interesting features. Many farmers sold livestock, this can be explained by the fact that they do not have a place to take them; and worst, livestock owners are paid very low for the livestock as buyers take advantage of the situation (Armijos and Few, 2015). Also, relatively few of them received a loan.[8]

Table 2. Responses to the March 2016 eruption

	%
Mutual assistance in the form of labor exchange	72.07
Reduced food expenses	67.57
Spent savings	63.06
Received assistance from the government	60.36
Sold livestock	50
Reduced health and education expenses	49.1
Received assistance from a church or NGO	24.77
Worked on other farmland (outside of family)	24.32
Changed of crops	15.77
Obtained a loan from friends or relatives	12.61
Obtained a loan from a bank or a cooperative	12.16
Received money from friends or relatives living in Ecuador	7.66
Received remittances	4.05
Sold farmland or land	1.35

N = 222

Logically, 45% respondents report the Tungurahua volcano to be very dangerous, 39% dangerous, 13% little dangerous and 3% not dangerous. Most thus estimate that the volcano constitutes a high risk. Even with this, people living on the slopes of the volcano overwhelmingly decided to stay despite the human and economic risks from eruptions and despite the government's program of household relocation to safe areas: 84% of the respondents in the sample of the risky zone say that their main residence is in exposed area although 50% of them have a residence in a protected zone. When asked if they would still be living in the exposed area as the volcano remains active, more than 94% of household heads said yes. The main reason that contributes to the reluctance to move 55.9% is related to economic opportunities, either because family income sources exist in the home location through farming, either because employment opportunities lack in other places or are inaccessible. In addition, most family members (women, children and elders) stay at least at night in the resettlement home and go back to farm their land during the day whereas male only stay in the risky villages. This might give a feeling that the family is safe from the volcano's threat. Other obstacles to relocation such as old age, lack of education, difficulties in renting houses, a dependent family member are also frequently mentioned (27% of answers). Finally, 11% said they have adapted to the ash fall so they did not need to relocate.

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[7] Previous studies show evidence that farmers also cope with shocks through land rental markets (Eskander and Barbier, 2016; Ward and Shively, 2015). However, we do not have such information in our data.

[8] Berg and Schrader (2012) analyzed the effects of volcanic shocks on the demand and access to credit in the area of the Tungurahua. Using a natural experiment, they found that the number of loans demanded increased in response of volcanic activity and that the access to credit depended on the extent of the client-bank relationship, even in the agricultural sector which is the most severely affected by volcanic shocks.

4. Why do farm households stay in the risky zone?

The literature has explored factors that could explain households' decision to remain in volcanic areas (See Section 1). Land illiquidity and labor immobility have received relatively little attention despite their potential to better understand the behaviors of households' living on the slopes of volcanoes.

4.1. Does the proximity of the volcano depreciate land values?

In the risky zone, all households in our sample are farmers and their main asset is land. Therefore, analyzing their behavior calls for an understanding of farmland values. To this end we use a hedonic pricing framework. Land is composed not only of characteristics relating to the productive quality itself, but also of characteristics determined by location. The latter includes a wide range of location-determined characteristics such as the quality of the environment (including proximity to the volcano), and the distance to markets or to main roads. The hedonic price model consists of the analysis of the price of differentiated goods based on their characteristics. Rosen (1974) formalized the model for real estate prices, which was further developed for agricultural land by Palmquist (1989) and Palmquist and Danielson (1989). The hedonic model consists of revealing the implicit prices of various attributes of heterogeneous goods. It implies that farmland is an heterogeneous good consisting of a set of characteristics Z = (z1,…,zk ,…,zK) sold in bulk. Plots are distinguished from each other, both through their intrinsic as well as extrinsic characteristics. The hedonic model calculates the implicit marginal price of these different characteristics from the overall price (value) P(Z) of the plot. At equilibrium, each implicit marginal price pk is equal to the marginal willingness to pay for this characteristic and is calculated, in the case of quantitative variables, as the derivative of the aggregate price P(Z) with respect to the quantity zk. The empirical calculation of different marginal implicit prices thus requires the estimation of the hedonic price function by regressing prices of agricultural land on their various characteristics. Here, we focus on land that is owned and cultivated by farmers.

During the survey, farmers where asked to report the per-cuadra (1 cuadra = 84 square meters) value of each plot of land they cultivate.[9] Table 3 provides the description and summary statistics of several intrinsic and extrinsic characteristics that explain farmland values. Annex 1 provides the regression results and implicit prices. The model explains 58.2% of land value variations. Since we estimated a log-log model, for continuous variables an 10% increase in the variable leads to 10*coeff % change in the value of cuadra; and for binary variables, the impact in % is measured by $100(e^{coeff}-1)$. The results support several commonly-held hypotheses about farmland prices. We find that the larger the surface of the plots, the lower the value per cuadra is. In the model, we have three accessibility variables that play a significant role in the formation of agricultural land prices. We find that poor access to parcels in case of rain lowers their value and the closer a plot is to the main road, the higher is its value. Construction is also an important variable that adds significant value to the land. Among plots on which there is a construction, 83% are dwellings and 17% are prefabricated house (*mediagua*). We introduced three variables

[9] There are several convincing arguments to say self-reported farmland values closely approximate their market value. First, since we focus here on farmers who own and cultivate their land, we can postulate that they are the best informed on the various attributes of the plots. In particular, the accumulated experience conveys information about the previously adverse conditions, i.e. ash fall, that have a plot-specific component. Second, farmers interviewed did not have any incentive to misreport the value of their land. Farmers are thus expected to be well informed about land prices.

that measure the productive potential of the plot, i.e., the reported quality of the soil, its slope and access to irrigation water. A flat land is positively valued compared to more sloping land. And both are negatively valued compared to a mixed slope. Soil quality is not significant, but it may be related to the fact that 91% are of good quality.

The most interesting and relevant result is that farmland in the risky zone has a negative premium of 21% compared to land in the control zone, ceteris paribus. This depreciated value of land near volcanoes means that farmland loses of its value to serve as an insurance mechanism, despite it being farm households' main productive asset. Households thus face several challenges. First, their land capital is degraded by the eruptions. Second, farmland is an illiquid asset. Third, even if households wanted to sell their land, they would suffer a loss of value estimated above, which would not allow them to acquire the same productive capital outside the risky area. Since this loss increases the cost of moving, this may reduce the attractiveness to move. In addition, acquiring information on the land market at a new location might not be so easy so that searching for a new land carries opportunity costs, transaction costs and uncertainty. This reinforces the option of staying at the current place of work.

Table 3. Summary statistics for the hedonic model

		Owned and cultivated plots in both zones				Control	Risky	
Variable		Mean	Std. Dev.	Min	Max	Mean	Mean	
ln_pricesur	Logarithmic transformation of the value per cuadra	0.95	1.41	-3.68	5.19	1.26	0.57	***
ln_superficie	Surface (in cuadra)	8.09	1.55	4.09	14.00	7.86	8.37	***
irrigation	=1 if irrigated	0.47	0.50	0	1	0.74	0.14	***
goodsoil	=1 if good quality (self-reported soil quality)	0.91	0.29	0	1	0.90	0.92	
tilt_flat	=1 if the tilt is flat	0.51	0.50	0	1	0.55	0.45	**
tilt_slope	=1 if the tilt is sloping	0.26	0.44	0	1	0.25	0.27	
tilt_ravine	=1 if the tilt is on a ravine	0.03	0.17	0	1	0.02	0.04	*
tilt_mixt	=1 if tilt is mixed	0.21	0.40	0	1	0.18	0.24	
construction	=1 if construction on the plot	0.70	0.46	0	1	0.75	0.64	***
rain	=1 if difficulty to access when it rains	0.36	0.48	0	1	0.33	0.38	
ln_road	Logarithmic transformation of the distance from the nearest road (km)	-3.30	3.39	-9.21	3.91	-3.81	-2.70	***
ln_canton_time	Logarithmic transformation of the distance from the nearest canton (min)	3.19	1.10	-9.21	4.79	3.21	3.16	
zonaland_risky	=1 if in the risky zone	0.45	0.50	0	1			
		N=535				N=293	N=242	

*** p<0.01, ** p<0.05, * p<0.1 indicate if the difference between the control and the red zone are statistically significant

Note: To allow the logarithmic transformation of *ln_road* and *ln_canton_time*, we added 0.0001 to all observations.

4.2. Geographical and occupational immobility

Labor immobility is an important issue in determining farmers' response to the volcanic threat. The more immobile labor is, the more difficult would be the change in both places of living and occupation. There is a fairly large body of empirical work on both aspects of labor immobility in rural areas.

Among all the factors that are known to attach people to a place and reduce mobility, the extent to which farming skills are transferable across space is a main concern that has recently received attention in the literature (Autor, 2013; Bazzi et al., 2016; Gathmann and Schönberg, 2010; Huffman and Feridhanusetyawan, 2007). Most crops are sensible to growing conditions such as soil conditions, soil management techniques, soil nutrient disorder etc. (Cox et al., 2006). Farming technical knowledge is thus usually associated with specific location and specific crop. As a result, farmers may encounter difficulties in transferring their human capital in safe locations where growing conditions might be different than in the originate one. As a result, a large productivity loss may occur that causes large foregone earnings. Barriers to skill transferability may thus imply an adjustment cost which is out of reach of most farmers (Gollin and al., 2014).

Labor immobility also refers to the difficulties in taking advantage of opportunities in other sectors in the nearby or distant areas. Numerous studies have examined the extent to which rural workers engage in nonfarm activities[10] as well as the rationale behind this behavior, well summarized by Ellis (1998).[11] It is now widely held that labor mobility depends on the availability of attractive nonfarm opportunities arising from a dynamic local economy and the capacity of household members to exploit these opportunities which, in turn, depends on their human, social and financial capital.

In the sampled areas, the majority of household members live with on-farm activities as their main occupation: nearly 90% of them declare working on their own farm whatever the zone where they live. However, in addition to working on their farm, household members engage in nonfarm work: 20.2% of household members declare a nonfarm occupation in the risky zone, 15.2% in the resettlement zone and 27.1% in the control one. These figures tend to suggest quite a lower degree of participation in the nonfarm labor market in resettlement and risky zone compared to the control zone. This result contradicts most findings in the literature that documents a positive relationship between risk exposure and participation in the nonfarm activities. But our finding could be explained by a selection bias, those who have chosen to stay in the risky areas may have specific characteristics. As we will see, this indicates strong barriers to the adjustment to risk exposure.

[10] Nonfarm activities include non-agricultural wage work and self-employment activities which generate income. Note that some activities linked to agriculture such as agro-processing, sales of agricultural products, or agricultural wage works are often undertaken by households. Since the analysis focuses on the occupational mobility out of agriculture, they have been excluded from the calculations.

[11] For a comprehensive survey of the determinants of labor mobility in rural areas in Latin America, see also the special issue of World Development "Rural Nonfarm Employment and Incomes in Latin America", published in March 2001.

Table 4. Characteristics of nonfarm occupations

	Risky zone	Resettlement zone	Control zone	All sample
Share of workers participating in (%)				
farm work	90.0	91.4	89.1	89.8
nonfarm work	20.2**(*)	15.2***	27.5	23.3
N = total number of workers	248	270	696	1214
Share of nonfarm occupation in (%)				
Sales and related occupations	42.0***	48.8**	66.5	59.6
Production, construction, transportation, repair	40.0**	31.7	25.7	29.1
Office and administrative support	2.0	1.0	0.0	3.0
Management, health, education, art, design	14.0	17.1	7.9	10.3
N= total number of nonfarm occupation	126	243	48	369
Share of nonfarm wage occupation in (%)				
same parish	54.5	26.1	42.3	41.2
same province	31.8	65.2	38.5	43.3
other province	13.6	8.7	19.2	15.5
N= total number of nonfarm wage occupation	22	23	52	97

*** p<0.01, ** p<0.05, * p<0.1 indicate if the difference between the risky/resettlement zones and the control are statistically significant. Stars in bracket refer to the difference between the risky and resettlement zone.

The range of nonfarm occupations appears rather limited: commerce is the main subsector that attracts workers in the three zones (66.5% of occupations in the control zone, 48.8% in the resettlement zone and 45.1% in the risky zone). Manufacture, construction and transport represents the second main sector of occupations, with 40% of occupations in the risky zone, 31.7% of occupations in the resettlement zone, and 25.7% in the control one. The third "sector" of occupation, but far behind the other two, includes all the occupations from managerial to medical and administrative occupations. This sector concentrates no more than 13.3% of occupations.

Most occupations are quite close to dwellings: 41.2% of nonfarm activities are undertaken in the same parish where the workers live, another 43.3% are undertaken in the same province and only 15.5% in another province.

Table 5 shows that the weight of agricultural-related occupations is much greater for landed households. Multi-activity as well as nonfarm occupation declines with landholding size: households whose landholding size falls in the first quartile have on average a higher number of workers engaged in nonfarm activities than those whose landholding size falls in the last quartile . Hence nonfarm activities look like an inferior good. Households who lack land and thus farm income are those who engage more in the labor market or develop nonfarm enterprises. Although the information on incomes is not available from survey data, the inverse relationship between land size and nonfarm labor tends to suggest that diversification away from farm labor is mainly driven by push rather than by pull factors. In such conditions, there is little incentive to live the agricultural sector.

Table 5: Average number of members working nonfarm per household

	Landholding size				All sizes
	<= 0.2 ha	0.2 - 0.74 ha	0.74 - 1.48 ha	> 1.48 ha	
Risky zone	2.00	1.85	1.62	1.22	1.72
N= total number of nonfarm workers	31	34	47	18	130
Resettlement zone	1.88	1.70	1.47	1.31	1.62
N= total number of nonfarm workers	49	10	38	26	123
Control zone	3.07	2.09	1.96	1.42	2.11
N= total number of nonfarm workers	67	183	142	59	451
All sample	2.36	1.96	1.96	1.63	1.95
N= total number of nonfarm workers	111	183	255	155	704

On the whole, diversification of economic activities appears quite low in our sample, in particular in the risky and resettlement zones. In most empirical studies, the drivers of geographical mobility imply many factors, among which the availability of jobs, the cost of commuting or moving, and the capacity of rural workers to take these opportunities.

The spatial distribution of economic activities and the resulting local labor market dynamism in nearby areas is a first main issue in understanding rural workers involvement in nonfarm activities. Access to a wide range of jobs for rural people depends on the availability of these jobs. A diversified local economy is better able to offer many jobs, and some industries offer jobs that are more flexible, better adapted to agricultural seasonality, and better suited with farmers' skill set. The survey does not provide information on the local labor market such as the conditions in nearby urban market centers or other prosperous villages. However, we have qualitative information on the main cities close to the survey areas. Baños, which is the nearest city of both risky and resettlement zones is a major tourist center of around 20,000 inhabitants so most jobs opportunities fall into leisure, entertainment and hospitality industry. These jobs require skills (communication, computer know how, interpersonal skills) that are far beyond the reach of workers who have a farming background. Riobamba is the capital city of the province Chimborazo and has 250,000 inhabitants. The city which is close to the control zone is a large market which support the demand for both agricultural and non-agricultural products and services that farm households are able to produce or supply. It is also expected to have a wider range of production activities and greater opportunities for nonfarm activities. This partly explains why the participation in nonfarm activities is higher in the control zone.

A second main source of labor immobility of rural workers comes from the fixed costs they incur when they enter the labor market. Among these costs, the commuting or moving costs associated to the distance between the residential and workplace is a key one. People living far from cities bear higher transport costs and have less information about employment opportunities either directly or through social networks. These costs clearly reduce the probability of wage employment. But individuals living in rural environments remain also constrained in their self-employment opportunities. Distance to a large urban center restrains the demand for non-agricultural products and services that farms are able to offer.

At first glance, the differences between risky, resettlement and control zone in terms of distance (by road) to main urban centers cannot be considered as an important impediment to nonfarm work. The communities of the risky zone are on average 45 km away from the closest city Baños whereas and resettlement zones are a little bit closer (23,3 km). The closest city of the communities of the control zone is Riobamba, which is only 12 km away. Both zones have access to relatively good paved roads.

Finally, many empirical studies show that labor mobility between occupations and sectors of the economy (agricultural and non-agricultural) is low when agricultural workers are concerned because they usually lack the skills to work in nonfarm jobs ILO, 2011). The noticeable differences in the time-allocation pattern between the three zones are consistent with the level of education of the rural labor force. Unskilled workers make up the vast majority of the workforce in the risky and resettlement areas where most workers have achieved only primary education. They thus have a poor retraining capacity or at a high cost. In comparison, educational attainment in the control zone is higher, so the capacity of household members to take nonfarm opportunities is better.

5. Discussion and Conclusion

Natural disasters, such as volcanic eruptions, impose severe non-productive and productive asset loss to affected populations. Dwellings, land, crops and livestock are damaged with every natural hazard. Despite these regular damages, some populations choose to live under the threat of volcanoes. In this paper we used primary data collected with farmers living under the threat of the Tungurahua volcano in Ecuador and with farmers living in a nearby control zone to examine farm households' behavior with the specific intention of proposing natural hazard-response economic policies. Our attention is particularly directed to the examination of households' main productive assets, i.e. farmland and labor.

Farm households living near active volcanoes face hard choices since the maintenance of livelihoods depends on the return on economic activities. Their decision to stay should be understood as the result of asset illiquidity and labor immobility. We have shown that farmers tend to own location-specific assets and thus would incur significant costs in moving. Assets, such as farmland that are not easily marketable (or to a low value) clearly restrict farmers' ability to exit their place of location. Then, farmers may lack resources to move or to change occupation. These barriers suggest that adjustment to volcanic shocks through the diversification of economic activities may be extremely difficult for some workers. Our paper thus complements anthropological, social and geographical approaches such as Armijos and Few (2015), Armijos et al. (2017), and Few et al. (2017).

Nonetheless, there are many good reasons for living near the Tungurahua. First, land on the slopes of the Tungurahua volcano is highly productive, with soils fertilized by ashes and a favorable climate explain. Second, efforts by Ecuadorian authorities to inform the population through the community-based network of vigias have helped people to return to their original homes with less risk in the volcanically threatened area around the Tungurahua (Stone et al., 2014). As a result, people tend to perceive the risk as acceptable. All this has thwarted the government's efforts to have risk areas residents evacuate and relocate to safe areas.

But current public policies in Ecuador are not sufficient because they adopt a disaster risk management approach, that is aid provided during emergency periods (Armijos and Few, 2015). Considering the impact of ash falls on productive assets, and constraints faced by farm households with respect to their occupational attributes, we argue that relocation policies should be complemented by interventions on land and labor markets to address natural hazards. There is a need for more integrated policies that account for land and labor specificities.

Existing research shows that agricultural growth has a much greater impact on poverty than growth in industry, manufacturing or services (Ravallion, 2001; Klasen & Reimers, 2017). Ash falls compromise agricultural production of farmers already burdened by poverty. Increasing agricultural productivity will increase household incomes, reduce poverty and thus will help to manage the inherent risks of agricultural production in areas threatened by volcanic eruptions. Enhanced agricultural productivity should also be passed on in land prices and compensate, at least partly, for the discount in land prices linked to eruptions. As there are so many aspects that determine agricultural productivity, there is a large scope for policy intervention. The uptake of new technologies such as use of improved seeds varieties, expansion of irrigation or the adoption of higher value crops depends foremost on the availability of technologies appropriate to local conditions. Scientists have the responsibility to provide information on what the suitable options are. Agricultural extension services, broad access to credit services and potentially crop and livestock insurance against volcanic shocks are also vital means to ensure a widespread adoption of productivity-enhancing technologies.

However, the poorest farmers might not have sufficient land or access to strategic inputs to escape poverty. Diversification of household income sources is another common means of managing the risks associated to eruptions. The principal policy challenge is how to unlock employment opportunities and ensure that farmers' access to these jobs is not rationed. Policies should therefore facilitate development of opportunities in neighboring areas in tourism, small shops, transport cooperatives, and small-scale mining. Common means of supporting enterprise development include improved access to credit services, markets, and technology as well as entrepreneurship training. Integrating rural workers into non- agricultural labor jobs would need households to transform their assets and skills. Less trained workers cannot hold a number of available jobs if they do not have the required skills. Public authorities may thus pursue a training policy in non-agricultural activities that would ease occupational mobility.

Policies implemented in the past must acknowledge the lack of realism of resettlement away from the dangerous zones without taking into account people livelihood opportunities. There is a balance to find between volcanic risk and livelihood transferability when designing resettlement schemes. Our findings are certainly relevant for other natural disasters, especially in areas under repeated shocks, such as landslides, floods and drought.

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Appendix

Annex 1. Hedonic pricing results and marginal effects

VARIABLES	Regression results	Variation of the value per cuadra due to a 10%	Variation of the value per cuadra due for having the characteristic
Ln_superficie	-0.636***	-6.36	
	(0.0327)		
Irrigation	0.152		16.42
	(0.107)		
Goodsoil	0.186		20.44
	(0.142)		
Tilt_flat[12]	-0.322***		-27.53
	(0.112)		
Tilt_slope	-0.619***		-46.15
	(0.133)		
Tilt_ravine	-0.0762		-7.34
	(0.308)		
Construction	0.266***		30.47
	(0.0932)		
Rain	-0.236**		-21.02
	(0.0923)		
Ln_road	-0.0224*	-0.22	
	(0.0124)		
Ln_canton_time	-0.0809	-0.81	
	(0.0586)		
Zonaland_risky	-0.239**		-21.26
	(0.113)		
Constant	6.369***		
	(0.332)		
Observations	535		
R-squared	0.582		

Robust ordinary least squares, log-log model
Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

[12] The control dummy is *tilt_mixt*.