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Abstract

This thesis aims to understand some of the effects of changes in intra-seasonal climate variability on household livelihoods in the Peruvian Andes. Concerns about the effects of climate change on the sustainability of Andean agricultural systems and, in general, concerns about the ability of rural households to adapt to increasing climate uncertainty motivate this thesis. The first study focuses on household decisions over crop portfolio diversification as a response to increasing climate variability. The study investigates whether Andean farmers respond by increasing crop diversity (measured by intercropping and crop diversification indices) or by switching to crops that better tolerate diverse environmental conditions. Based on fixed effects models that use a district panel of 1994 and 2012 agrarian censuses, the study finds that households in colder areas (<11˚C during the crop growing season) adapt to increases in climate variability by concentrating their portfolio into more tolerant crops and reducing intercropping (a practice potentially efficient at controlling pest and disease). This effect is especially strong in the Southern region (more indigenous, less integrated to markets). Taking a broader approach, the second study focuses on Andean rural households in general, investigating whether households adapt to increasing climate variability by concentrating more into non-farm income generating activities (relative to farm activities), and whether spatially distant family networks facilitate this adaptive strategy. Six economic outcomes are modeled in this study: non-farm income shares, non-farm working hours share, farm and non-farm income levels, and farm and non-farm working hours. Based on generalized linear models that use household information representative of rural provinces of the Andean region, the study finds that households adapt differently across the region. While households in the colder areas of the Central and Northern Andes (below 13˚C during the crop growing season) tend to increase non-farm income as climate variability increases, households in the South show no discernible response. The study results suggest that spatially distant family networks facilitate non-farm opportunities to households facing increasing temperature variability in the Central and Southern Andes. This thesis complements previous studies by providing robust and regionally representative evidence on households' nonlinear response to climate variability. Furthermore, given that Andean households received little-to-no help to adapt to climate change during the period under analysis, this study informs about household autonomous adaptation to climate change and raises concerns on current adaptation responses that may hamper the sustainability of Andean household livelihoods in the face of climate change.

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1 Introduction

The Andes is one of the regions most affected by climate change in the world and rural household livelihoods are particularly vulnerable. Not only there is extensive quantitative evidence of changes in climate conditions in the Andean region -such as the increasing temperatures leading to accelerated glacier retreat-, but also qualitative case studies report household perceptions of higher intensity of- and uncertainty about- extreme climatic events, more uncertain hydric regimes, warmer days and colder nights, among other changes. Furthermore, Andean households, and farmers in particular, are highly vulnerable to these changes due to their limited productive assets, access to markets and timely information on climate and market prices to transition into more productive, less vulnerable to climate risk, income generating strategies. This thesis aims to complement previous literature on household adaptation to climate change by studying household adaptive strategies with representative household socio-economic information and local climate estimates[1].

The thesis is composed of two studies. The first study focuses on household decisions over crop portfolio diversification when climate variability increases, whereas the second one focuses on the effect of such increase on the relative participation of non-farm income sources in household livelihoods. Although each study is presented in an independent article -with its full abstract-introduction-literature review-methods-results and discussion structure[2] - both were conducted with the same conceptual framework in mind[3], similar econometric identification strategies and a common goal. Therefore, their findings are jointly interpreted in the hope to improve our understanding of Andean households' adaptive responses and economic outcomes amid climate change.

The first study focuses on farm household response to intra-seasonal climate variability (measured by the temperature range during the crop growing season). The focus is placed on crop portfolio diversification strategies. It is noteworthy that most of the literature on the effects of

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[1] Less than 3% of farm households had received technical assistance in the previous year, according to 2012 census reports. Therefore, changes in household strategies (after controlling for confounding factors) when climate variability increases are considered adaptation strategies.
[2] The first one was published by World Development (https://doi.org/10.1016/j.worlddev.2019.104740) and the second one is under review by the Journal of Development Studies.
[3] The standard conceptual framework used for rural households, characterized by the non-separability between consumption-leisure and production decisions and unitary household assumptions.

climate change on agriculture focuses on impacts over yield of major world crops (maize, wheat, rice and soybean) in monocrop systems. The studies on more complex, diversified livelihoods, with low input cropping systems like those typical in mountain areas are mostly case studies and many of them use self-report of household perceptions about changes in climate (represented by categorical indicators in many cases). Three research questions are explored in the first study of this thesis: (i) do households increase the degree of diversification of their crop portfolios -as measured by the Herfindahl index- (standard economic theory suggests that diversification may efficiently minimize climate risk if individual crops suffer differently from climatic changes)?, (ii) do households concentrate more on crops that show to be more tolerant to heterogeneous environmental conditions -crop tolerance is measured by a co-occurrence Simpson index proposed by Ponce and Arnillas (2018)-?, and (iii) do households increase the allocation of farm land to intercropping (a farm practice that, when adequately implemented, can lower vulnerability to crop pest and disease)? The study estimates fixed effects models using a district panel of the 1994 and 2012 Agrarian Censuses matched with district climate estimates obtained by Ponce, Arnillas and Escobal (2015)[4]. The latter are also used in the second study. Climate estimates used in the analysis consist of 30-year averages of mean temperature, climate variability (temperature range: max-min) and mean precipitation, all of them estimated for the trimester November-January.

The second study takes a broader approach considering Andean rural households in general[5], and focusing the analysis on the relative importance of non-farm activities in household income generating strategies (which may include both farm and non-farm sources). The analysis introduces two factors which are prevalent in several developing rural economies but have been excluded from previous literature on the determinants of non-farm income (at least partially, due to lack of representative data): (i) -the previously mentioned- local intra-seasonal climate variability (and other climate features), and (ii) spatially distant, strong ties (increasingly important due to population mobility caused by the internal conflict and increasing connectivity between rural and urban areas). Two research questions are explored in this study: (i) do households concentrate more into non-farm activities (relative to farm work) when facing increasing climate

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[4] As explained in the following chapters, these estimates are based on daily information of the trimester November-January from 1964 to 2012, gathered by SENAMHI across the country. The methodology used to estimate 30-year averages indicators at district level follows the methodology used by Lavado, Avalos and Buytaert (2005) for the Peruvian chapter of the Evaluation of the Economics of Climate Change commissioned by the Inter-American Development Bank and the Economic Commission for Latin America and the Caribbean.

[5] The previous study focused exclusively on farm households (working their own farm), who represent 77% of Andean rural households. In the second study farm income can be obtain through wage or self-employment (85% of Andean rural households reports some type of farm income, either wage, self-employment or both).

variability? and (ii) do spatially distant, strong ties (direct family) facilitate this adaptive strategy? The main household outcomes under analysis are the proportion of non-farm income and of non-farm working hours relative to household labor income and household working hours, respectively. Complementarily, the study explores the role of climate variability and distant, strong ties on those outcomes measured in levels: farm income, non-farm income and the number of working hours allocated to farm activities and to non-farm activities. The analysis uses the largest rural survey implemented in Peru -representative of rural areas at provincial level-, the EPHR 2017 (for its Spanish name, *Encuesta Provincial de Hogares Rurales*). This survey was implemented by the INEI (Instituto Nacional de Estadística e Informática)[6] and gathered information on household labor income for over 120 thousand households in rural areas. The study focuses on 63,725 households of the Andean region. In spite of its cross-section nature, the survey offers key information on province-level productivity measures for farm and non-farm sectors (rarely available for rural areas) and, more importantly, it allows to estimate heterogeneous parameters across the Northern, Central and South domains of the Andean region. This is key to the analysis given the different climate patterns, geography and connectivity, and socio-economic dynamics across these domains. Generalized linear models with family distributions and link functions that fit each outcome were used in this study.

The hypothesis of this thesis

The hypotheses of this thesis are as follows:

- Farm households adapt to increasing climate variability by reducing their exposure to climate risk[7]; that is, by favoring crops and activities that are less likely to be affected by extreme climate events and, in general, by more variable temperatures. In terms of crop portfolio decisions, three options that can help reduce climate risk are: diversifying more their crop portfolios (to reduce total risk), increasing the portion of cultivated land allocated to intercropping (a cropping practice that, when adequately implemented, help reduce the incidence of pest and disease), and shifting their portfolio toward crops that better tolerate environmental diversity (which includes

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[6] This survey visited 120,012 rural households across Coast, Andean and Rainforest regions.

[7] IPCC defines risk as follows: "The potential for consequences where something of value is at stake and where the outcome is uncertain, recognizing the diversity of values. Risk is often represented as probability or *likelihood* of occurrence of hazardous events or trends multiplied by the *impacts* if these events or trends occur. In this report, the term *risk* is often used to refer to the potential, when the outcome is uncertain, for adverse consequences on lives, livelihoods, health, *ecosystems* and species, economic, social and cultural assets, services (including environmental services) and infra- structure. *{WGII, III}*" (IPCC, 2014: 127) While the probability of occurrence of extreme events is not controllable, households can reduce their exposure to climate risk by choosing crops and activities that are either less likely to be affected by an extreme event or less affected by such event.

climate conditions). In terms of income generating activities, households reduce their exposure to climate risk by increasing their participation in non-farm activities (increasing both non-farm income and non-farm working hours). It is worth to mention that farm activities in the rural Andes are key to household livelihoods (and in many cases non-farm income sources are associated with processing farm goods), especially for food security reasons and limitations to embark in highly profitable non-farm activities, so the expected increase in non-farm activities is not massive.

- Distant, strong ties (direct family living in a distant area) facilitate household adaptation strategies, by enhancing economic opportunities that would otherwise be unknown to the household. Given that spatially distant, strong ties do not share local climate hazardous events, and access different networks, they provide households with information on economic opportunities that their local network may not know of (seasonal migration jobs, new technologies to reduce climate risk, information about markets and prices) as well as potentially reduce households transaction costs in distant markets.

- Household adaptation is heterogeneous across Northern, Central and Southern regions, which differ in topography, accessibility to cities and regional markets, labor and land market dynamism and in institutional arrangements of control and access to natural resources key to farm activities.

- Farm household adaptation (especially in crop portfolio decisions) is more substantial in colder areas than it is in warmer areas, because their mean temperatures are closer to zero and an increase in the probability of extreme climate events (caused by an increase in climate variability) is more likely to lower crop yield or crop survival.

Identification strategy

These two studies share a common strategy to econometrically identify the role of intra-seasonal climate variability on household economic outcomes (diversification of crop portfolios and relative importance of non-farm activities in household labor income). Climate conditions included in the analysis refer to the crop growing season, represented by the trimester November-January[8]. Given that 77% of rural households in the Andean region are farmers[9] (EPHR 2014), climate conditions during the crop growing season play a key role in work and resource allocations across activities as well as in diversification of crop portfolios. As temperature variability

[8] As will be mentioned in Chapter 2, although the start of the rainy season varies across the Andean region (between September and November), by November it is well established across the region and lasts until March-April.

[9] 85% of rural households in the Andes obtain labor income from farm jobs either wage or self-employment.

increases, households face a wider range of possible temperatures and a higher probability of facing extreme climate events during critical crop growth stages, and therefore farm activities become more vulnerable and uncertain. Each chapter discusses the specific mechanisms through which climate variability affects the outcomes under analysis, but I would like to briefly mention two broad mechanisms. First, household expectations about climate conditions (and how uncertain these are) during the following crop growing season affect rural household decisions on participation, technologies and resource allocation across income generating activities. Therefore, it is not surprising to find several studies analyzing the effect of climate conditions and climate change on household strategies based on households' self-report about changes in local climate conditions and their (coping or adaptation) economic decisions implemented in response to such changes. This line of analysis, however, raises endogeneity concerns, given that household expectations about climate depend not only on objective climate conditions observed in previous years but also on other individual factors such as farmers' experience, education, information (usually accessible through local networks), among others. Second, local climate conditions affect local (and possibly regional) market prices, labor demand and supply in different sectors of the economy, and consequently affect household economic outcomes under analysis (such as the household share of non-farm labor income) beyond their effect on household decisions[10]. Furthermore, some of the climate events identified by some as increasing climate variability (such as an increase in extreme climate events) may be the result of a distributional shift of temperatures instead of an increasing temperature variability.

So, what does intra-seasonal climate variability measures and how do the present studies measure its effect? Climate is usually defined as "the joint probability distribution over several weather parameters, such as temperature or wind speed, that can be expected to occur at a given location during a specific interval of time" (Carleton & Hsiang, 2016: 1), this interval is usually of 30 years (IPCC, 2014b)[11]. The present studies focus on climate parameters that characterize the distribution of temperatures and mean precipitation. Given that "the distribution of temperatures often resembles a normal distribution" (Folland, Karl, & Salinger, 2002: 155), it is possible to

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[10] Given that two areas with higher climate variability may differ in the weather shocks realizations in a particular year, the second study models control for actual weather shocks that occurred in the previous year that could have affected economic outcomes beyond what would be expected from local climate variability.

[11] According to the IPCC (2014b), climate refers to "the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation, and wind."

characterize it with its mean and variance. Therefore, the identification strategy uses the 30-year averages of mean temperature and temperature range (max-min, as proxy for variability [12]) [13]. To clarify the importance of distinguishing between the effect of temperature mean and variability, Figure 1 from Chapter 2 is reproduced here. One of the consequences of higher temperature variability is the higher likelihood and severity of an extreme event. However, as shown in Figure 1, an increase in the mean with no change in variability of temperatures may also explain that scenario (in this case, an extreme hot event). Furthermore, it is reasonable to expect that the effect of an extreme event, for instance a cold event (hail or freeze) will have harsher consequences in areas with colder mean temperatures compared to areas with more mild temperatures. Section 2.3.2. presents in detail the identification strategy and the implications of changes in the parameters of the distribution of temperatures.

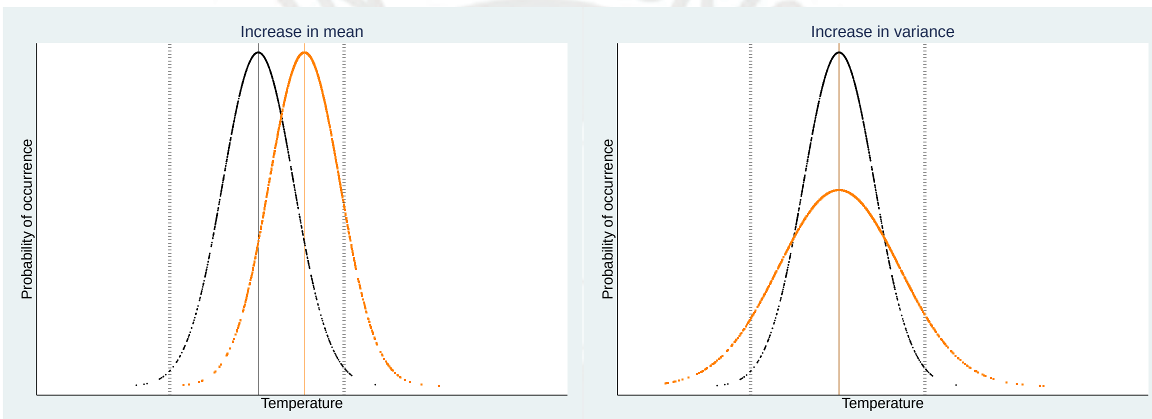

Figure 1 (Chapter 2). Schematics showing two distributions of temperature for a particular location (adapted from IPCC Figure 2.32 (Folland et al., 2002)). T_0 (in black) and T_1 (in orange) represent the distribution for the initial and the final period, respectively. The first panel shows an increase in mean temperature, with no change in variance. Although there is no change in variance, the probability of having high (low) temperature extremes is higher in T_1 (T_0) than in T_0 (T_1). The second panel shows an increase in temperature variability, with no change in mean. The probability of experiencing high and low temperature extremes increase in the second period due to change in variability. The gray vertical lines show the minimum and maximum temperatures that would occur during the crop growing season with 99% probability under T_0 climate parameters (the one that farmers know). Either a change of the distribution mean or variability would lead to an

[12] Temperature range is used as a proxy for the standard deviation of the temperature distribution. Given the normality of temperatures, approximately 95% of the occurrences should fall within the range of +/- 2 standard deviations from the mean, and 99% within +/-3.

[13] Unlike temperature, the available evidence suggests that precipitation follows a non-Normal distribution, and its characterization is far more complicated. The only estimate for the Peruvian Andes that seem robust enough for the analysis is the 30-year-average mean precipitation, which do not allow further exploration of the role of precipitation but is used as a control to better assess the effect of temperature.

increasing climate risk for farmers. Appendix 2 shows three scenarios consistent with an increase in mean and variance (with different changes in minimum and maximum temperatures).

Thesis structure

This manuscript includes three chapters besides this introduction. Chapters 2 and 3 present the two independent studies and follow a similar structure. Each chapter starts with an abstract that summarizes the study, followed by an introduction that discusses the motivations, research questions and briefly outlines the contributions of the study in the context of the existing literature on the topic. The following section focuses on discussing what we know so far about the channels through which climate variability may affect the economic outcomes under study. Given the nature of each topic, this section draws on literature from different disciplines; while the study on crop diversification strategies required to review literature from crop sciences, ecology, social sciences, agricultural economics and climate economics, the study on non-farm income diversification in rural areas required an additional focus on economic sociology, network analysis and rural studies. Both chapters include a section that describes the data and estimation methods used in the analysis, special attention is placed on the ability to isolate the effect of climate variability from other factors influencing household decisions. Fixed effects models are estimated in the first study and generalized linear models are estimated in the second study. The last section of each chapter discusses the results and concludes. Chapter 4 presents the main conclusions of this thesis. Although the detailed conclusions of each study are discussed in Chapters 2 and 3, Chapter 4 seeks to offer a broader view of the strategies that rural households in the Andes would implement to adapt to increases in climate variability based on such findings. The chapter emphasizes the heterogeneity of adaptive household responses found across subregions and, within subregions, across the temperature gradient. As usual, further research is needed to better understand adaptation strategies and identify policies that may enhance their efficacy, and this chapter highlights some that could help overcome some limitations and further investigate key issues associated with this thesis.

2 Intra-seasonal climate variability and crop diversification strategies in the Peruvian Andes: A word of caution on the sustainability of adaptation to climate change [14]

Abstract

Agricultural systems are highly sensitive to climate change. Most studies focus on the effect of heat and water availability on crop yields, but little is known about the impact of changes in intra-seasonal climate variability (particularly challenging in mountain regions). Also, beyond the effect on crop yields –mostly focused on single cropping systems and major world crops- little analysis has been done on more complex, diversified and low-input cropping systems like those prevalent in the Andean region. This study investigates whether Andean farmers respond to increasing climate variability by increasing crop diversity (measured by intercropping and crop diversification indices) and by switching to crops which better tolerate heterogeneous environmental conditions. Since previous studies show that crop diversification fosters resilience of agricultural systems, decreasing crop portfolio diversity in an increasingly variable environment may challenge farms sustainability. The data used in the analysis combines district-level socio-economic information from two agrarian censuses (1994 and 2012) with district-level climate estimates of mean temperature, temperature range and precipitation (averages for periods 1964–1994 and 1982–2012). Based on fixed effects models that allow for sub-region parameter heterogeneity, I find that an increase in intra-seasonal climate variability leads farmers in colder areas (<11 ˚C during the growing season) to concentrate their portfolio into more tolerant crops and reduce intercropping (a practice potentially efficient at controlling pest and disease). This effect is especially strong in the Southern region (more indigenous, less integrated to markets). These results complement previous studies by providing robust and regionally representative evidence on small-farmers' nonlinear response to climate variability. Furthermore, given that Andean farmers received little-to-no help to adapt to climate change during the period under analysis, this study informs about farmers' autonomous adaptation to climate changes and raises concern on current adaptation responses that may hamper agricultural system's sustainability in the face of climate change.

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[14] This study was published by World Development 127 (2020) 104740, https://doi.org/10.1016/j.worlddev.2019.104740. A previous version was uploaded online as a progress report, at http://www.grade.org.pe/wp-content/uploads/GRADEai36.pdf.

2.1 Introduction

There is extensive evidence of climate changes in the Andean region (Dasgupta et al., 2014; Trasmonte, Chavez, Segura, & Rosales, 2008; UNEP, 2013; Vuille, Bradley, Werner, & Keimig, 2003). Accelerated glacier retreat is the most notorious effect of increasing mean temperatures, but higher intensity and unpredictability of climatic events (precipitation and extreme temperatures) have also been documented and directly affect agricultural outcomes. Previous studies argue that impoverished rural households (like most smallholder Andean farmers) are highly vulnerable to climate change due to their limited access to timely information about climate and market prices, their limited assets and the inherent vulnerability of agriculture (their main source of livelihood) to environmental stress (Dasgupta et al., 2014). This study investigates Andean farmers' response concerning crop portfolio composition to increases in intra-seasonal climate variability.

There is a vast literature on the impact of climate change on agriculture (Dell, Jones, & Olken, 2014; Hsiang, 2016; Lobell, Schlenker, & Costa-Roberts, 2011; Porter & Semenov, 2005; Rötter, Appiah, et al., 2018; Shi, Tao, & Zhang, 2013). Most of these studies have focused on estimating the impact of increasing mean temperatures on crop yield for major world crops: maize, wheat, rice and soybean. Studies range from experimental scientific studies, focused on the biological response of crop performance (growth, development, survival) to changes in temperature or water availability (Porter & Semenov, 2005; Rötter, Appiah, et al., 2018; Wheeler, Craufurd, Ellis, Porter, & Vara Prasad, 2000), to econometric studies based on short term weather fluctuations and aimed at unveiling the net effect of change in climate conditions on crop yield or output (Dell et al., 2014; Hsiang, 2016; Shi et al., 2013). More recently, a growing recognition of the importance of climate variability has shifted the focus towards the nonlinear association between climate conditions and crop yield, growth, development or survival. Scientific experiment-based studies find evidence of a nonlinear relationship between temperature and crop performance (Porter & Semenov, 2005; Wheeler et al., 2000). This is also found for other living species (Briga & Verhulst, 2015, for zebra finch (bird) mortality, Vasseur et al. , 2014, for 38 ectothermic species, Paaijmans et al. , 2010, for rodent malaria transmission intensity, among others). Studies that allow for heterogeneous nonlinear effects of temperature find that the strength and direction of the response to climate variability may depend on mean environmental conditions (Briga & Verhulst, 2015). Statistics-based studies on the effects of extreme climate events and climate variability (Schlenker & Roberts, 2009; Taraz, 2018) have been recently complemented by studies on the effect of compound heat and dry extreme climate events (Lu, Hu, Li, & Tian, 2018; Zscheischler et al., 2018).

In spite of this progress in understanding the biological response of major cropping systems (maize, wheat, rice, soybeans, among other few) to climate change, it is important to note that most of this research has focused on major crops grown in temperate regions. Rötter, Hoffmann, Koch and Müller (2018) highlight two key limitations of using available crop models to understand complex systems -like the Andean- characterized by crop and crop-livestock diversification, intercropping and limited inputs. First, there is little experimental and statistical research on many important tropical crops; and second, "crop models are not capable of capturing the multi-species interactions within one 'field' and the associated services delivered" (Rötter et al., 2018: 259). From the Ecology literature, Lin (2011) argues that such complex, diversified agricultural systems tend to be more resilient than monocrop systems and delineates the underlying mechanisms that explain such potential advantage. For instance, crop diversification can reduce the incidence of disease and pests, buffer climate stress and increase production (Lin, 2011: 185). Lin's argument is consistent with previous studies on earlier Andean civilizations, which emphasize the importance of adaptive agricultural practices to achieve food security in a difficult environment. Crop diversification, selection and domestication of tolerant crops and varieties, and water management technologies ("waru-waru", terraces, among others) were some of the key agricultural practices that Andean societies developed to manage climate risk and steep terrain and take advantage of diverse microclimates (Earls, 2008; Escobal & Ponce, 2012; Tapia Núñez & Fries, 2007; Winterhalder, 1994). Even though this traditional knowledge has been an asset to Andean farmers when facing climate stress, according to surveys and several local studies, farmers find the increasing severity and unpredictability of extreme events, as well as the unpredictability of hydric regimes quite challenging (Earls, 2008; Escobal & Ponce, 2010; IGP, 2005). This study investigates whether Andean farmers currently respond to higher climate variability by increasing crop diversification and switching to crops that better tolerate environmental diversity, practices that according to previous literature should increase their cropping systems' resilience. Although we would expect a positive answer, several reasons could explain a negative one, including the decreasing family labor available for agricultural activities, the increasing non-farm work opportunities -typically less vulnerable to climate risk-, the increasing access to food markets that can ensure food security regardless of local climate risk, potentially weaker community institutions that lose influence in household production or technological decisions as well as in organizing communal work, among others.

To analyze the effect of changes in (growing season) intra-seasonal climate variability on crop portfolio decisions, three indicators of crop portfolio composition are considered in this study: (i) the degree of crop diversification (within the farm, measured by the Herfindahl or Simpson index), (ii) the size of farmland allocated to intercropping (within-plot diversification), (iii) and the relative importance of tolerant crops in the crop portfolio. The latter is measured by a crop tolerance index, developed by Ponce and Arnillas (2018), which quantifies the relative tolerance of a crop to diverse environments (the higher it is, the more diverse are the environmental conditions that the crop can tolerate; the lower it is, the less likely it is that the crop survives changing environmental conditions). Information on crop portfolio and other farmers' characteristics was obtained from two Peruvian agrarian censuses (1994 and 2012). As usual, climate is defined here as "the joint probability distribution over several weather parameters, such as temperature or wind speed, that can be expected to occur at a given location during a specific interval of time" (Carleton & Hsiang, 2016: 1). Three climate parameters of this distribution are used, all of them are 30-year average trimester estimates: mean temperature, temperature range (max – min) and monthly precipitation. Temperature range for the trimester November-January (1964-1994 and 1982-2012) is used as proxy for (growing season) intra-seasonal climate variability for each census year. These climate parameters were estimated by Ponce, Arnillas and Escobal (2015) based on daily information from 1964 to 2012 (250 meteorological stations) and aggregated at district level to match farmers' census data. To estimate the effect of climate variability across the mean temperature gradient this study uses Fixed Effects models that require weaker assumptions on omitted variables. I further explore potential parameter heterogeneity across sub-regions to account for additional omitted variables issues.

This paper is organized as follows. Section 2 presents a brief discussion of the literature on crop diversification and selection of tolerant crops as a means to adapt to climate change. This section explains several mechanisms through which crop diversification affects crop viability and productivity, and the challenges that farmers face to diversify crops appropriately (information, experimentation, complementary assets). The third section describes the data and the methodological strategy. The fourth section discusses the results, and the final section summarizes the main findings.

2.2 Literature review of crop diversification as a means for adapting to changing climate conditions in the Andean region

There is a vast literature on adaptation to climate change, especially in the agricultural sector. The Fifth Assessment report of the Intergovernmental Panel on Climate Change (AR5) highlights that the literature on developing countries' adaptation in rural areas has increased substantially in recent years, in particular for agriculture, water, forestry, biodiversity, and fisheries, whereas most of the examples of rural area adaptation documented by the previous Fourth Assessment (2007) had focused on developed countries. Agricultural adaptation includes traditional practices developed long ago as a response to weather and climate variability[15], as well as new technologies and resistant varieties. Adaptation practices include crop diversification, diversification into alternative varieties of specific crops (drought-resistant, early maturing, etc.), changing fertilization rate or amount or timing of irrigation, implementing shading and wind breaking measures, conservation agriculture (soil protection, agroforestry), and rainwater harvesting, among others (Dasgupta et al., 2014: 638-640; Dell et al., 2014: 757-759[16]; Easterling et al. 2007: 294-295; Porter et al. 2014). Furthermore, Dasgupta et al. (2014: 638) argue that diversified farms (those combining livestock and crop farming) are more resilient than specialized farms, and that income diversification into off-farm activities is also a form of adapting to the increasing climate risk.

2.2.1 What are the mechanisms in place that make crop diversification a potentially effective way to face climate change?

The mechanism through which crop diversification improves resilience is based on the role of biodiversity in ecosystem functioning. Lin argues that crop diversification makes agricultural systems more resilient to climate change by enhancing their ability to avoid outbreaks of pests and diseases (the likelihood of which increases with higher temperatures and humidity), as well as by reducing the risk of losing crop production due to greater climate variability and extreme events

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[15] AR4 reports that "[m]any of the autonomous adaptation options (…) are extensions or intensifications of existing risk-management or production-enhancement activities" (Easterling et al. 2007: 294).

[16] Dell et al. (2014) survey studies on the relationship between weather and agriculture, among other activities, from the Economics literature. Although the studies focus on short-term climate events (weather), the authors raise useful points for climate-related analysis.

(Lin, 2011: 183). Several types of crop diversification (spatial or temporal) have been developed by traditional and modern agricultural systems. For example, traditional systems include crop diversification across plots and crop rotation across years. Spatial diversification of crops can be implemented at different scales: (i) within the crop, by introducing several crop varieties; (ii) within the plot, by companion cropping or intercropping; (iii) within the agricultural unit, by introducing several crops though not necessarily side by side; or (iv) at the landscape level, by integrating several production systems like cropping, livestock raising, and agroforestry (Lin, 2011: 184). The present study is focused on (ii) and (iii), as well as on the selection of crops relatively more tolerant to diverse environmental conditions.

According to Poveda, Gómez and Martínez (2008: 132) there are three main mechanisms through which vegetation diversity affects crop pests: by disrupting the pest's ability to locate the host plant, by increasing the pest's mortality, or by repelling the pest. By reviewing 62 studies, some of which include intercropping practices, Poveda, Gómez and Martínez show that diversification practices improved pest control in half of the studies (specifically by enhancing natural enemies in 52% of them and reducing herbivores in 53%—, the latter especially in intercropping systems), and increased crop yield in one third of the studies. The authors find 50% success in pest control to be lower than expected and discuss possible explanations for such results in detail. Several recommendations follow from their discussion; notably, the need to choose the "right kind" of diversity. The authors mention the study by Heemsbergen et al. (2004) that suggests that it is the functional differences between species, instead of the mere number of species, that enhance overall ecological function. Based on that study, Poveda, Gómez, and Martinez (2008: 134) argue that each species' contribution to the functional groups in a community may explain the link between biodiversity and ecological services (like pest control). Therefore, identifying the right combination is key to achieving the goals of pest control and yield enhancement, a necessary caveat for understanding Andean farmers' limitations to adapt current intercropping practices to new climate conditions in the absence of information and technical assistance for choosing new right combinations.

Empirical studies focused on the Andean region support the conclusions drawn by Lin (2011) and Poveda et al. (2008) regarding the efficiency of crop diversification for adapting to climate change. Tapia and Fries (2007) emphasize that Andean agricultural systems are characterized by extensive use of crop diversification. The authors mention a community in Cusco (Southern Andes) that allocates over 50% of their plots to intercropping, with many plots producing maize alongside other introduced species such as *haba* (fava beans) and *arveja* (peas). Tapia and Fries argue that cultivating maize together with 10 percent of quinoa improves pest control. They also mention some cases in Cajamarca (Northern Andes) where livestock-cropping farms intermingle maize and quinoa, and add tarwi at the edges so as to avoid damage from the farm's livestock. Similarly, Gianoli et al. (2006) evaluate maize production in the Urubamba Valley (Cusco, Southern Andes) within different cropping systems. Their experimental design consisted of monoculture plots of maize, maize intercropped with beans, and maize intercropped with beans and associated (naturally occurring) weeds. They find that intercropping is more efficient than monoculture in controlling pests without an effect on maize yield, and conclude that intercropping is an efficient alternative to the use of pesticides. Complementarily, Gianoli et al. (2006) mention that previous studies have documented that maize-bean and maize-bean-kiwicha, native to America, are common intercropping combinations among small farmers in the Peruvian Andes (284). They also discuss previous studies conducted in other regions of the world (Altieri & Whitcomb 1980, Altieri 1994, Altieri & Letourneau 1999), which show a lower density of insect pests when maize is grown in diversified cropping systems (Gianoli et al. 2006: 284).

As mentioned in the Introduction, there is a vast literature about the impact of climate change on the individual crop yield of major crops (maize, wheat, rice, soybeans). Although not the focus of the present study, this literature identifies causal mechanisms underlying the effect of temperature changes on crop growth. Craufurd and Wheeler (2009) argue that the effects of increasing temperatures on crop growth are difficult to assess given that additional factors (besides mean temperature) vary simultaneously as part of climate change (precipitation patterns and timing, frequency of extreme events, CO2 concentration, management practices). However, they emphasize that the impact of climate change on crop growth is key for assessing its effect on crop productivity. The authors argue that the "timing of flowering, a critical stage of development in the life cycle of most plants when seed number is determined, is important for adaptation both to the abiotic stresses of temperature and water deficit, and to biotic (pest and disease) constraints (Curtis, 1968) within the growing season" (Craufurd & Wheeler 2009: 2530). The authors refer to several studies showing this and highlight that successful adaptation practices include selecting varieties with suitable flowering and growth cycle durations. Based on these studies, the econometric analysis in Section 4 uses climate information for the trimester when crops are growing on most Andean farms.

The right combination of crops (diversification) and cultivation techniques (intercropping) to enhance pest control and yield in the context of climate change also involves identifying and combining crops that tolerate changing environmental conditions. As previously mentioned, climate change is affecting both biotic and abiotic factors in the crop system (Lin, 2011); thus, assessing which crops are tolerant to new conditions and unpredictability is not easy, for farmers or scientists. To identify differences in crop tolerance to environmental changes and allow for comparisons between crop portfolios (moving from single crop systems to more complex systems), Ponce and Arnillas (2018) propose the use of an index based on the concept of the ecological niche of a species (a crop in this case). A species ecological niche represents the environmental conditions where a species can survive. These environmental conditions include both biotic (abundance of prey and predators) and abiotic conditions (temperature, salinity, humidity, among others). The larger the ecological niche, the more generalist the species is (and thus the higher tolerance it exhibits to environmental changes). In the following sections, we analyze a proxy indicator of a crop's relative degree of tolerance, to complement the study of the effects of intra-seasonal climate variability on crop diversification and intercropping practices.

2.2.2 To what extent do farmers adapt their crop portfolio to climatic changes? How do farmers' perceptions of climate change affect adaptation decisions?

The literature on agricultural production strategies shows that the degree of crop portfolio diversification is determined by a wide set of economic and social factors, such as the farmer's access to markets and access to information about technologies, alternative crops, and relative prices, among others. Researchers from both social and natural sciences have emphasized the importance of crop diversification as an effective strategy for adapting to climate change (Charles and Rashid, 2007; Bradshaw et al., 2004; Tuteja, Gill, and Tuteja, 2012; Lin, 2011). To what extent do households perceive climate change and adjust their decisions in consequence?

Several qualitative studies—especially in African and Latin American countries— document rural households perception of climate changes (Escobal & Ponce, 2010; Thomas et al. 2007; Vergara, 2012; Postigo, 2012; Mulwa, Marenya, Rahut, & Kassie, 2017, among others). Postigo (2012) conducts a study of high-altitude Andean pastoralists, regarding their perceptions and responses to climate change. He also reviews previous studies in the Southern Andes, including those by Espillico Mamani and Apaza (2009), and Sperling et al. (2008) for Puno communities, which report increasing concern about droughts, night frosts, floods, wind, and hail, as well as the study by Moya and Torres (2008) for Cusco, which documents perceptions of a higher frequency of freezing nights (Postigo, 2012: 33). Documented responses to such changes range from no adaptation to migration. Furthermore, researchers have warned about other global changes that also need to be considered -along with climate change- in order to more effectively address the challenges that farmers (currently and in the future will) face (Glave and Vergara, 2016; Postigo and Younge, 2016).

While many qualitative case studies have been conducted about farm-households' perception of climate conditions (precipitation timing, and likelihood of extreme events such as droughts, frost, or hail during the growing season) and their adaptation responses to such conditions, studies based on regionally representative information are quite scarce. As follows, we discuss studies based on large surveys (although not all of them representative of specific regions).

Mulwa, Marenya, Rahut and Kassie (2017) study adaptation in Malawi using a survey of 1700 households, which provides information on household perception of local climate changes in the previous 10 years as well the number of times that the household faced climate risks (droughts, floods, crop pests, diseases, hailstorms or other shocks). Based on a cross-section multivariate Probit, the authors investigate the factors that prevent households to respond to such climate risks with potentially effective adaptation strategies: using drought tolerant crop varieties, using pest and disease tolerant varieties, changing timing of cropping activities, diversifying crop enterprises and investing in soil and water conservation technologies. The authors find that plot characteristics, credit constraints and lack of access to climate information limit households' ability to adapt to climate risks.

Kurukulasuriya and Mendelsohn (2008) take a different approach, combining the agro-economic and Ricardian model frameworks to identify the impact of climate change on farmers' crop revenues unveiling adaptation. Based on data from 5000 farmers across 11 African countries, the authors find that climate does affect farmers' crop choice and highlight the limitations (potential overestimation) of climate change impact models that assume no adaptations of crop portfolios by small farmers. Deressa, Hassan, and Ringler (2011) model adaptation of Ethiopian farmers as a two-step process, with a first period when perceptions of climate are formed, and a second one when perception-based adaptation decisions are made. The study is based on household data gathered from 1000 mixed crop and livestock farmers located in the Nile basin of Ethiopia, and climate data estimated by the University of East Anglia. According to this study, perceptions of climate change (including temperature and precipitation patterns over the past 20 years, summarized as a dummy of whether the household perceived changes) are significantly influenced by the household head's age and knowledge about climate change, social capital, and agro-ecological settings. Adaptation measures (including tree planting, soil conservation, planting of different crop varieties, early and late planting, and irrigation use) were summarized by a dummy variable. According to their findings, the implementation of such adaptation measures depends on several factors including household head's education and sex, number of household members, diversification into livestock farming, use of extension services, and access to credit. In addition, like Kurukulasuriya and Mendelsohn (2008), Deressa, Hassan, and Ringler find that adaptation increases with temperature. It is worth noting that although the use of dummy variables to summarize perceptions of climate change and choice of adaptation practices oversimplifies the potentially high heterogeneity across households and practices, it is an interesting study that shows the role that individual characteristics play in farmers' perceptions of climate change, as well as on the type of adaptation practices implemented as a response to such perceptions.

More recently, Call, Gray and Jagger (2019) analyze the case of 850 smallholders in Uganda using information on household livelihoods, including on-farm and off-farm activities, for years 2003 and 2013, and 10 years climate data (mean annual precipitation and temperature and one-year and ten-year anomalies). Three on-farm strategies are considered in the analysis: number of cultivated crops, use of fertilizer, and on-farm working hours. The authors find that smallholders manage to cope with higher temperatures in the short term, by increasing the number of crops and applying fertilizer, as well as increasing off-farm activities. However, the authors suggest that smallholders struggle in the longer term and warn on the sustainability of farm activities if increasing temperatures, as expected, continue to increase.

Fankhauser (2016) surveys the literature on adaptation to climate change and notes that most studies on private (sometimes called autonomous) adaptation are focused on agriculture. The author emphasizes on the need to acknowledge that adaptation requires planning, coordination, knowledge, resources, and to discard the notion of spontaneous adaptation. Fankhauser (2016) highlights that short-term responses to weather variability include diversifying into non-farm activities, reducing farm size and, when available, using weather insurance. Also, as he discusses a study by DiFalco and Veronesi (2013) for Ethiopia, Fankhauser (2016) shows that adaptation effectiveness may require complementary measures. In the Ethiopian case that they study, changes in crop varieties were only effective for increasing net revenue when complemented by water and soil conservation measures. The need for simultaneous adaptation measures stresses the importance of considering socio-economic barriers to adaptation, especially challenging for small farmers in poverty—like the majority of Andean farmers in rural Peru-.

2.3 *Data and methods*

2.3.1 Data

Crops, socio-economic characteristics, and institutions

Two Peruvian Agrarian Censuses were used in this study. These censuses were conducted by the National Institute of Statistics and Informatics (INEI) in 1994 and 2012. Georeferenced information was available at the district[17] level. Since some district borders changed between 1994 and 2012, 1800 districts with rural areas listed in the Agrarian Census 2012 were grouped into 1732 new "districts", ensuring the spatial comparability of district codes between 1994 and 2012[18]. Two thirds of these districts have most of their territory in the Andean region.

The Agrarian Censuses provide information about key household characteristics, such as the head of household's education level, sex, age, and adscription to a peasant community (which has legal control over the access and use of local natural resources in certain areas), household members, land size, access to and use of production technology such as tractors and certified seeds, use of irrigation systems, access to technical assistance, the list of crops cultivated in household plots, and income diversification into off-farm activities, among other factors.

Climate (estimates)

Data on climate conditions in the Peruvian Andes consist of district-average estimates obtained by Ponce, Arnillas and Escobal (2015). Using daily temperature and precipitation information gathered by the National Service of Meteorology and Hydrology (SENAMHI) in over 250 Andean weather stations, the authors estimated 30-year mean temperature and precipitation at the district level for the periods 1964-1994 and 1982-2012. These estimates followed the methodology used by Lavado, Ávalos, and Buytaert (2015) for the Peruvian chapter of the Evaluation of the Economics of Climate Change project commissioned by the Inter-American Development Bank and the Economic Commission for Latin America and the Caribbean.

Three 30-year climate parameters of trimester November-January were used in this study: mean temperature, intra-seasonal temperature range (calculated as the difference between maximum and minimum temperatures for the trimester and period under analysis), and average

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[17] Districts are the smallest units of political-administrative demarcation in Peru.
[18] Only districts with crop farming activity in both census years were included in the analysis.

precipitation. These parameters were calculated at district level excluding climate conditions in areas over 4800 meters above sea level (m.a.s.l.), since no agricultural activity is likely to be biologically viable above that level. Above that altitude we find glaciers that have dramatically changed due to climate change in the Andean region. Despite the effects of the accelerated glacier retreat on river water discharge, this analysis excluded such dramatic changes since they would bias the analysis of farmers' decisions.

2.3.2 Methods

As it was previously mentioned, Crop Science and Ecology literatures show that crop portfolio diversity induces resilience in agricultural systems exposed to environmental stress (including high climate variability) (Gianoli et al., 2006; Lin, 2011; Poveda et al., 2008; Tapia & Fries, 2007). In increasingly variable environments with higher risk of extreme temperatures, intercropping and crop diversification reduce incidence of pests and diseases and vulnerability to extreme cold temperatures (Gianoli et al., 2006; Tapia & Fries, 2007, Lin, 2011; Poveda et al., 2008). Increasing temperatures also affect the timing of flowering and may shorten crop development stages reducing crop yields, at least for some varieties; whereas increasing temperature variability may increase yield variability (Craufurd & Wheeler, 2009; Porter & Semenov, 2005). Thus, choosing more resilient crop (species, varieties), which can grow in diverse environments, may improve farm production when temperature variability increases.

Of course, these scientific findings do not necessarily translate into farming decisions in complex socio-ecological settings. The estimation strategy needs to control for both, factors that affect farmers perceptions about local climate and factors that affect farmers production decisions. First, we need to acknowledge that farmers' response to changing climate conditions is mediated by their perceptions and, as mentioned in Section 2, such perceptions may differ between farmers that face the same climate conditions. Following previous literature, the estimations control for factors that could explain differences in perception, such as experience (approximated by age), education and available information (mostly facilitated by social networks, NGOs and governmental agencies), among others (Deressa, Hassan, & Ringler, 2011). With regards to the general farmers perception, it is worth mentioning that previous qualitative studies confirm Andean farmers perception of climate changes. For example, farmers in some areas of the lower Central Andes perceive higher incidence of pest and disease in areas with increasing temperatures and less-predictable precipitation (Escobal & Ponce, 2010), whereas farmers in higher areas of the

Southern Andes perceive increasingly colder nights and warmer days (Postigo, 2012; Sperling et al., 2008).

Second, as discussed in Section 2, crop portfolio decisions are not exclusively determined by household perceptions of environmental stress. Other key determinants of crop portfolio decisions include farmers' assets and preferences, access to markets (land, inputs, products, labor and credit), their expectations on (uncertain) market prices, and their access to alternative income generating opportunities (Asfaw, Scognamillo, Caprera, Sitko, & Ignaciuk, 2019; Michler & Josephson, 2017). These factors also change in heterogeneous ways across the region. Moreover, according to previous literature, the response to climate variability (adaptive capacity) depends on household assets as well as on structural and institutional factors. Some adaptation measures include changes in crop portfolio (species and varieties), timing of farm activities and technological change (irrigation, soil conservation and new inputs). Agroecological characteristics, access to credit, timely access to climate information, household head education and sex, number of family members, diversification into livestock farming and use of extension services have all been identified by previous literature as potential determinants of climate adaptation measures (Call, Gray, & Jagger, 2019; Deressa, Hassan, & Ringler, 2011; Mulwa, Marenya, Rahut, & Kassie, 2017).

It is important to emphasize that the estimated effect of climate variability on crop portfolio composition using district level data is valid to infer household behavior only if such effect is homogeneous across households (Garrett, 2003). If households' response to climate variability is heterogeneous, then the estimated effects cannot be extrapolated to specific households (this wrong interpretation is usually called aggregation bias or ecological fallacy). In this study I explore parameter heterogeneity between districts located at different sub-regions (North, Central, South). This allows to (partially) capture differences in land market dynamics (considerably higher in Northern and Central areas), road connectivity and relative access to markets and public goods (lower in the Southern region), socio-cultural practices in farm communities, among other institutional and agroecological factors, as well as regional differences in households characteristics that may influence systematically climate responses [19]. However, I am not able to explore any source of response heterogeneity within the district partition. This is an important limitation. Different sources of heterogeneity can be hypothesized. For instance, households that have more experience, skills and information may perceive climate changes more accurately than

[19] Deressa, Hassan and Ringler (2011) find for Ethiopia that adaption increases with temperature.

their peers and prepare more effectively for the growing season. Social capital, participation in peasant communities and associations can reduce the experience gap. Moreover, even if perceptions are homogeneous and realistic, households may respond differently to climate changes depending on their ability to implement the necessary crop portfolio adjustments (difference explained by their access to markets, experience and information, and capital). Therefore, the reader must be aware that the estimated effect is an average of potentially heterogeneous parameters. I discuss some plausible scenarios for the Andean region illustrating such heterogeneity in the results section.

Indicators of crop portfolio composition (dependent variable)

Three indicators of crop portfolio composition were analyzed: the degree of crop diversification, the size of farmland allocated to intercropping practices, and the relative tolerance of crops to diverse environmental conditions. Each indicator provided complementary insights on farmers' rationality when choosing a specific crop portfolio in response to higher climate variability.

a. The Herfindahl index (or Simpson index) was used to measure the degree of concentration of a household crop portfolio.

$$H_j = \sum_{i=1..N} s_i^2$$

The index ranges from 1/N to 1, with N representing the number of crops cultivated by farm-household j. s^i represents the land share allocated to crop i. The higher the index, the higher the concentration of a crop portfolio.

The analysis that follows used the district's average index, which is calculated as the average H_j weighted by the respective cultivated land size of farm j.

b. The cultivated area allocated to intercropping in the district was used to measure crop diversity within plots (Andean farmers hold an average of 2.8 plots per farm). According to (INEI, 2014), the crops registered in the censuses as cultivated using intercropping practices (also called companion cropping) are grown simultaneously with one or more additional crops, intermingled in an orderly manner in the same plot. These crops can be a combination of perennial and/or annual crops (for example, maize and beans, or coffee and plantains).

c. A co-occurrence index was used to compare the relative tolerance of cultivated crops to diverse environmental conditions (including climate). This crop index was adapted by Ponce and Arnillas (2018) following the methodological framework developed by Fridley, Vandermast, Kuppinger, Manthey and Peet (2007) to measure a species ecological niche breadth.

The ecological niche breadth of a species "… represents the range of environmental conditions where a species can survive (such as temperature, humidity, and salinity, as well as abundance of prey, predators, or mutualists) (Rodriguez-Cabal et al. 2012, Stachowicz 2012, Afkhami et al. 2014)" (Ponce & Arnillas, 2018: 11). As with any species, a crop with a wider ecological niche should have higher odds of survival when the environment changes.

The co-occurrence index identifies the set of crops that are produced alongside a focal crop in each district and measures how heterogeneous those sets are across the districts where the focal crop grows. Crops that are produced alongside very different sets of crops across districts are more likely to survive a wider range of environmental conditions than those found with the same set of crops across districts. For instance, crops like maize and beans, which have a higher tolerance index than maca or golden-berry, are found with very different sets of crops across districts. According to the ecological niche breadth framework, maize and beans are more likely to thrive in different environmental settings than maca and golden-berry, which typically grow alongside similar sets of crops across districts. Ponce and Arnillas (2018) estimated crop tolerance indices for 252 crops cultivated in different environmental conditions across the country (Coast, Andes and Rainforest regions). To avoid bias due to differences in crop abundance, as well as to avoid spurious results due to focal crops that are not widely produced across districts, the authors followed the methodological adjustments proposed by Fridley et al. (2007) [20].

The district-level crop tolerance index analyzed here was calculated as the average of the crop level index weighted by the size of farmland where each crop is cultivated in the corresponding district.

Intra-seasonal temperature variability (explanatory variable)

The explanatory variable of interest in this study is the intra-seasonal variability of temperatures during the crop growing season. The higher the expected variability, the higher the climate risk faced by farmers when deciding on crop portfolio strategies for the future growing

[20] Appendix 1 summarizes the methodology.

season. An increase in temperature variability increases the likelihood that an extreme event (hot or cold) occurs and, in general, increases the probability that the weather conditions during the crop growing season are less stable (deviating from the comfortable mean). To analyze the effect of an increase in temperature variability on crop portfolio decisions at district level we need to consider the implications of other changes in the distribution of temperatures that may also affect the likelihood of variable and extreme weather.

Climate parameters -usually consisting of 30-year estimates of mean and variability of temperature, precipitation and wind- characterize the probability distribution of weather conditions in a particular period and location (IPCC, 2014; Carleton & Hsiang, 2016). According to the IPCC, "the distribution of temperatures often resembles a normal distribution" (Folland, Karl, & Salinger, 2002: 155). This means that characterizing changes in the distribution of temperatures requires comparing the two moments of the distribution, the mean and the variance, in two time periods.

In this study we explored econometrically the effect of changes in temperature variability (approximated by temperature range, the difference between 30-year average maximum and minimum temperatures[21]) controlling for mean temperature. Figure 2.1 (adapted from Folland et al., 2002) shows why controlling for mean temperature is crucial to identify the effect of changes in variability. Farmers response to an increase in climate variability can be understood as a response to increasing climate risk due to a higher probability of facing extreme events (besides more diverse temperatures) during the growing season. As the first panel of Figure 2.1 shows, an increase in climate variability affects the probability of facing extreme events, both hot and cold, and in general makes the weather less stable. In turn, an increase in the mean (with no changes in variability), also increases the probability of hot weather during the growing season, as well as the probability of facing record hot weather which could cause crop loss.

[21] Temperature range is used as a proxy for the standard deviation of the temperature distribution. Given the normality of temperatures, approximately 95% of the occurrences should fall within the range of +/- 2 standard deviations from the mean, and 99% within +/-3.

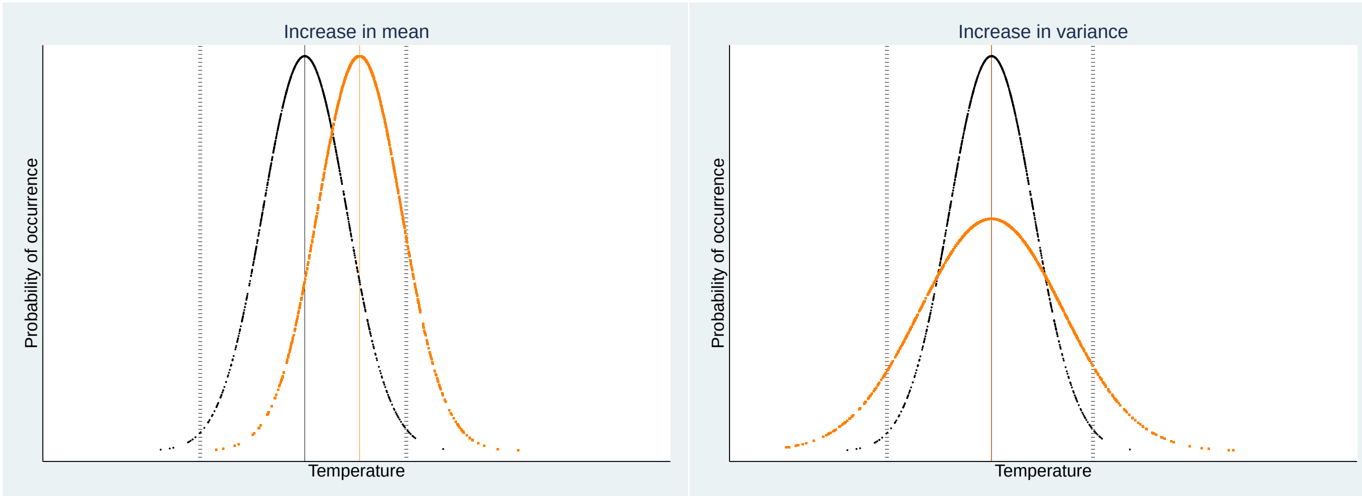


Figure 2.1. Schematics showing two distributions of temperature for a particular location (adapted from IPCC Figure 2.32 (Folland et al., 2002)).

T0 (in black) and T1 (in orange) represent the distribution for the initial and the final period, respectively. The first panel shows an increase in mean temperature, with no change in variance. Although there is no change in variance, the probability of having high (low) temperature extremes is higher in T1 (T0) than in T0 (T1). The second panel shows an increase in temperature variability, with no change in mean. The probability of experiencing high and low temperature extremes increase in the second period due to change in variability. The gray vertical lines show the minimum and maximum temperatures that would occur during the crop growing season with 99% probability under T0 climate parameters (the one that farmers know). Either a change of the distribution mean or variability would lead to an increasing climate risk for farmers. Figure 2.8 of Appendix 2 shows three scenarios consistent with an increase in mean and variance (with different changes in minimum and maximum temperatures).

As we will discuss in the following section, Andean climate estimates show a general increase in the long-term temperature mean and a heterogeneous pattern of change in temperature variability. Also, primary data from meteorological stations[22] (monthly average of temperature mean and temperature range for the growing season of each year during the period 1964-2012) show statistically significant time trends. According to these stations, between 1964 and 2012 growing season temperatures in the Andean region show increasing means (statistically significant in 70% of the stations) and heterogeneous changes in variability (30% show a positive trend and 20% a negative trend) (Figure 2.2). Increasing variability was recorded in a higher proportion of stations in the Southern (30%) and Central (40%) areas than in the Northern stations.

[22] Meteorological stations are not representative of the Andean region. Climate estimates discussed in the following section and used in the regressions are. The advantage of meteorological stations data is that it allows to identify time trends using monthly information for each year between 1964 and 2012. It complements and confirms the trend found with climate estimates.

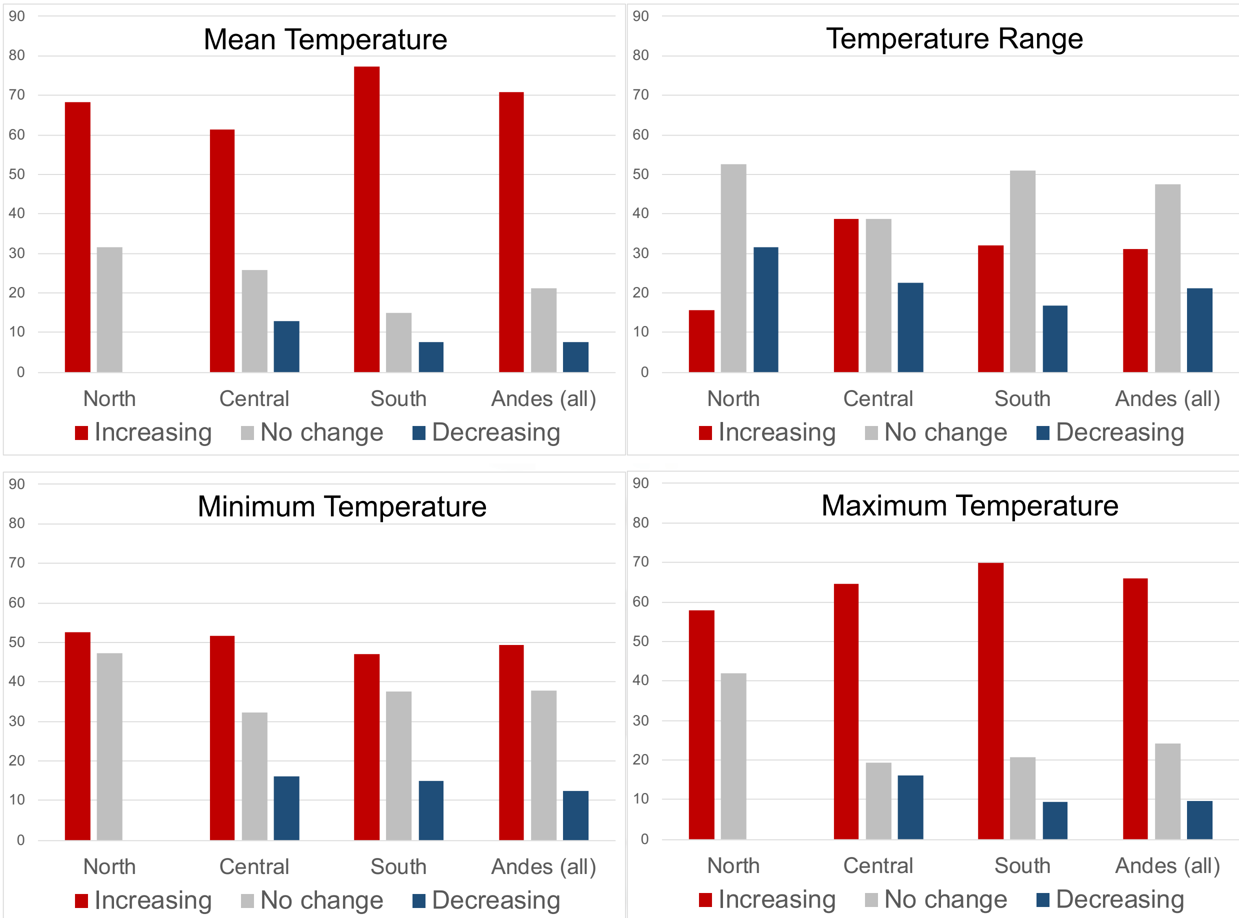


Figure 2.2. Proportion of meteorological stations with statistically significant trend in temperature indicators (1964-2012). Trimester November-January (crop growing season).

Econometric specification.

The effect of intra-seasonal climate variability on each of the three indicators associated with crop portfolio composition (Herfindahl index, crop tolerance index, and farmland allocated to intercropping), D_{it}, is estimated by taking advantage of the panel structure of the district data, using the following reduced form equation:

$$D_{it} = \alpha + TR_{it}\beta_1 + T_{it}\beta_2 + (TR_{it} * T_{it})\beta_3 + P_{it}\beta_4 + x_{it}\beta_5 + z_i\beta_6 + \mu_{it}$$

$$\mu_{it} = v_i + \varepsilon_{it} \quad , \quad \varepsilon_{it} \sim i.i.d.$$

$$t = 1994\,, 2012$$

TR_{it} , T_{it} *and* P_{it} represent three climate parameters characterizing climate during the growing season in district *i* at time *t*. TR_{it} represents temperature range (proxy for climate variability, estimated as the difference between the 30-year average estimates of the maximum and minimum temperatures at district *i*, previous to time *t*); T_{it} and P_{it} represent 30-year average estimates of temperature and precipitation, respectively. The effect of climate variability is estimated using a Fixed Effects model and comprises a linear effect (β_1) and a nonlinear effect across the mean temperature gradient (β_3). This nonlinearity allows to capture other unobservables correlated with altitude (main covariate of temperature in the estimations by Ponce et al. (2015)) that may explain heterogeneous responses to climate variability.

Besides climate, other factors affecting perceptions and crop portfolio decisions are included in the model. Farmers' decisions are based on their knowledge and experience in agriculture, including how to cope with risk and uncertainty, as well as how to get and efficiently use information about climate, markets and technologies. Other assets influence their decisions, such as equipment, land, and social capital as well as other household members available to help with farm field work and commercialization strategies. It is important to note that social capital is critical in some parts of the Andes, especially in the South, where peasant communities ("*comunidades campesinas*") still control the access to and use of key agricultural assets such as land and water in important sectors of the sub-region. Social capital can also play an important role in access to markets, inputs, and new production technologies. Finally, especially for farmers who live in poverty, external actors such as government projects and NGOs play a key role in facilitating (sometimes inducing) access to new technologies or new crops (or varieties). Observable time variable factors are represented by x_{it}.

The error term consists of an unobserved time-invariant idiosyncratic component v_i and a time-variant idiosyncratic component ε_{it}, which is assumed to be i.i.d. as usual. As is well known, the fixed effect estimator does not require the strong assumption of zero correlation between v_i and the time-invariant variables x_{it}. Thus, for example, we do not need to assume (as usual in cross section models) that education is not correlated with entrepreneurship or risk aversion, or that areas where cultural backgrounds influence the community's economic dynamics are uncorrelated with prevalent climate conditions.

Each regression was weighted by the district's cultivated area to avoid potential over-representation of districts with few farmers, to obtain estimates representative of the Andean region. The estimation adjusted standard errors to deal with potential heteroscedasticity and serial intra-panel correlation.

Finally, it is worth noting that the Andean region has different patterns not only in terms of climate conditions, but also in terms of socio-economic characteristics, market dynamics, and institutional arrangements for control of and access to natural resources. Therefore, it is plausible that the effect of intra-seasonal climate variability on farmers' crop portfolio decisions also differs across areas, even when controlling for mean temperature. Accordingly, the fixed effects' estimates for the Andean region are complemented by sub-region-specific estimates that allow for heterogeneous parameters across Northern, Central, and Southern areas.

2.4 Results and discussion

As mentioned before, the Andean region is quite heterogeneous in terms of farmers' socio-economic characteristics, cropping strategies and biophysical conditions including climate. In this section I discuss the study's findings about the role of climate conditions on farm-households' crop portfolio decisions. Particular attention is given to the November-January trimester (the first of the two rainy trimesters), when crop flowering and maturation phases start in the majority of the region. First, I characterize climate heterogeneity and changing patterns across the Andean region, as well as household characteristics and production strategies. In the second part, I discuss the estimation results of the role of intra-seasonal climate variability on crop portfolio decisions, controlling for both time-variant and time-invariant confounding factors.

2.4.1 Descriptive profile of climate and farm households in the Andean region

Climate in the Andean region

With a territory ranging from 500 m.a.s.l. to 6768 m.a.s.l., climate in the Andean region is highly heterogeneous. The following characterization of the Andean region excludes areas over 4800 m.a.s.l and discusses averages weighted by district's cultivated area to adequately represent the climate conditions that Andean farmers face during the crop growing season.

On average, climate conditions in the Northern Andes are warmer and less variable than in the Central and Southern Andes. The dry season is the coldest, with temperatures ranging from 2 to 17, -4 to 13, and -9 to 13˚C in the Northern, Central, and Southern areas, respectively. In turn, during the rainy season (November-April) mean temperatures range from 9 to 20˚C in the North, from 5 to 18˚C in the Central part, and from 4 to 17˚C in the Southern part (Figure 2.3). Minimum temperatures between November and January (after crops sowing) range from 4 to 15˚C in the North, 0 to 11˚C in the Central part, and -2 to 13˚C in the Southern sub-region. Given the high sensitivity of crops to close-to freezing temperatures, an increase in temperature range may challenge agricultural sustainability in the Andean region. In addition, the increase in hot temperatures can increase the likelihood of crop pests and disease (Escobal & Ponce, 2010).

As previously mentioned, one of the hypotheses of this study is that farmers respond differently to an increase in climate variability (which leads to an increase in climate risk) depending on whether they are located in cooler or warmer areas. Is there a systematic correlation between temperature average and variability? Are warmer areas in the Andes also less risky in terms of climate variability during the crop growing season? Figure 2.3 shows this is the case in the Northern, warmer sub-region, but no systematic relationship is found in the South or Central Andes.

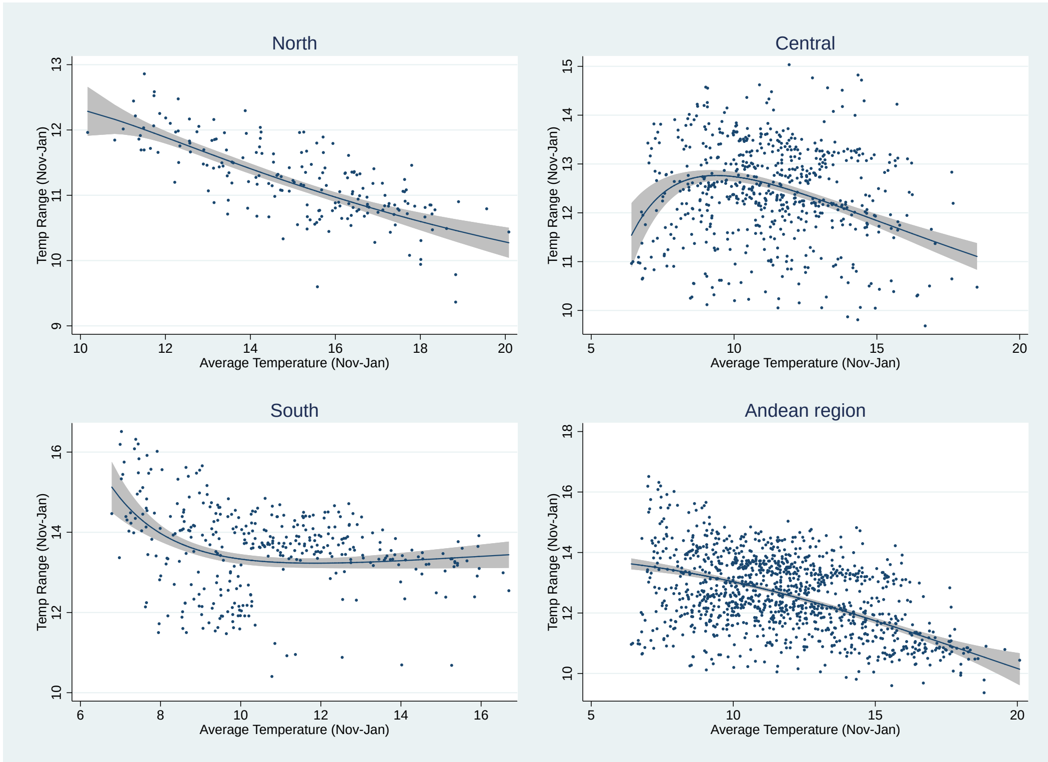
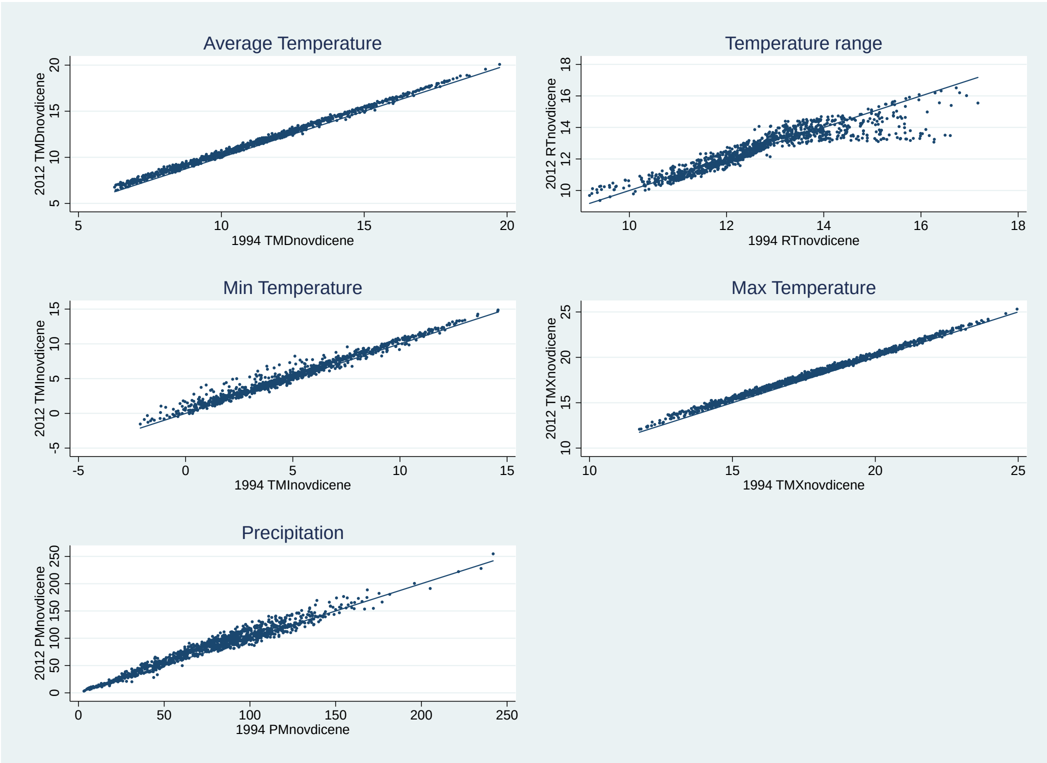


Figure 2.3. Temperature range and average temperature in the Andean region for the November-January trimester (2012), by sub-region.

Note: The fractional polynomial fit was estimated by weighting districts based on their cultivated land. In the Andean region as whole, there is an inverse relationship between average temperature and range. This is true for all four trimesters. However, when we isolate the Northern sub-region, this relationship disappears for all trimesters except for the coldest. Source: Based on district climate indicators estimated by Ponce et al. (2015).

Climate change. Climate estimates for the rainy season in the Andean region support farmers perception of systematic changes in climate, in particular of higher variability in temperatures, with less stable and predictable conditions for the growing season. While 30-year averages of mean temperature and maximum temperature in the growing season have increased throughout the region (on average 0.4˚C higher in 2012 as compared to 1994), minimum temperature, temperature range and monthly precipitation show heterogeneous trends (Figure 2.4).

a. November-January trimester



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b. February-April trimester

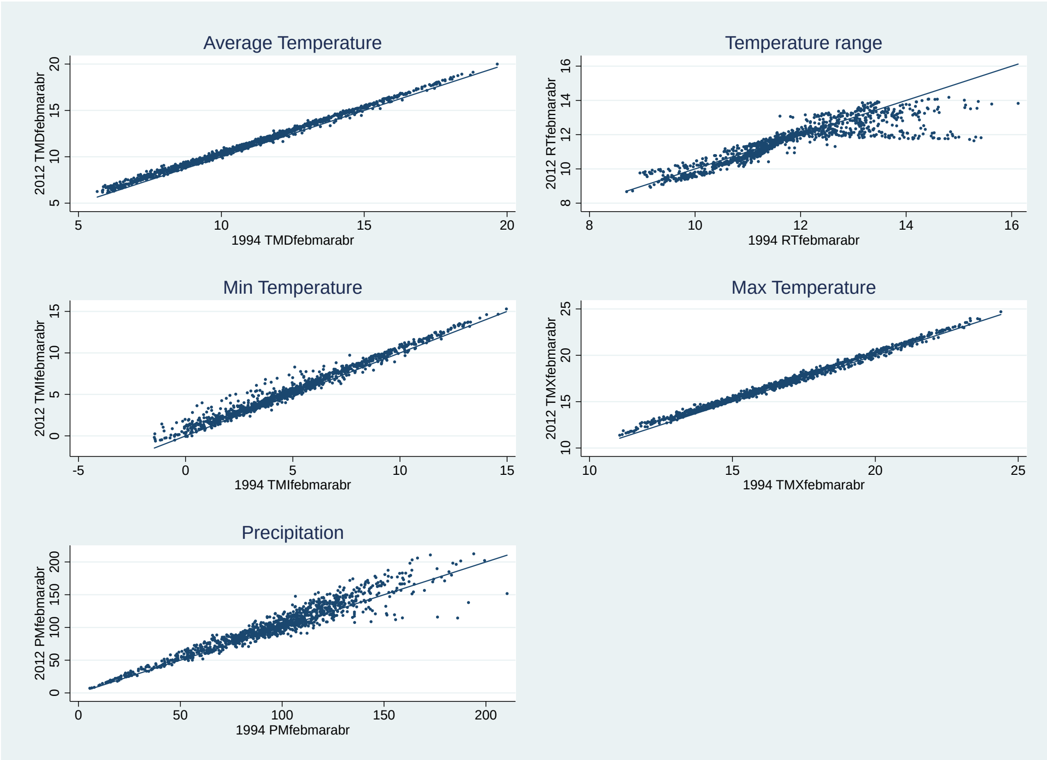


Figure 2.4. Climate change in the Andean region: mean temperature, temperature range, minimum and maximum temperatures, and precipitation during the trimesters November-January and February-April (1994 and 2012), Andean region.

Note: The 45˚ line represents no change in the climate indicator. Source: Based on district-level climate indicators estimated by Ponce, Arnillas, and Escobal (2015).

Hydric regime. Although the start of the rainy season varies across the Andes (between September and November), by November it is well established across the region, and lasts until March-April. Climate estimates show that precipitation in the Northern region has increased relatively more than the Central and Southern sub-regions in the last twenty years [23]. It is worth to mention that the strong impact of global warming on accelerating glacier retreat has caused decreasing water availability in some areas under glacial influence, whereas others are reaching the peak phase and still enjoy an increasing amount of water (Ramos and Vergara 2017). In areas with no major influence of glaciers the hydric regime can also be quite heterogeneous. Given that 60% of agricultural land depends exclusively on precipitation in the Andean region, it is key to

[23] As mentioned before, in agriculture the timing of rain can be as important as the amount (Vergara 2012). However, there is no information available to discuss changes in timing at the spatial and time scales so as to be representatively compatible with this study. Vergara (2012) conducted a qualitative study in the Central Andes, and discussed the weather-related challenges faced by farmers in some communities, including that of rain timing uncertainty.

consider both precipitation patterns and access to irrigation to account for water availability throughout the region.

Farm-households in the Andean region

Along with changes in climate conditions, Andean households' livelihoods have changed in the last decades. Although own-farm income is still the most important income source for most farm-households, off-farm income sources are increasingly important (Escobal, 2001; Ponce, 2018)). This is partially explained by the improvement in spatial connectivity, increased access to markets, growth of intermediate cities, and internal migration with subsequent strengthening of distant social networks (Ponce, 2018). Households demographics profile has also changed. Andean farm-household heads are, on average, more educated and slightly older than their peers were in 1994. The proportion of female-headed farm-households is 11% higher than before, and the average number of household members is 30% smaller. However, these changes have not been homogeneous across the region.

Table 2.1Table 2.1 shows the average demographics of Andean farm-households in 2012. According to this profile, in 2012 an average Andean household was headed by a 50-year-old man who had completed primary school at most and had an average of 3 family members. This average profile, however, hides important differences across the region and different trends across time. As Table 2.1 shows, Central and Southern farm-household profiles were similar in 2012, but Northern farm-household heads were on average less educated and younger than their Central and Southern peers.

Due to their potential effect on Andean households' livelihoods and adaptive abilities, some changes in the household profiles are worth highlighting. As previously mentioned, female-headed households increased by 11% between 1994 and 2012. This change was driven by the Central sub-region (15% increase), where we also found the highest increase in household head's average education level (27% increase in household heads with formal education beyond primary school) and the largest reduction in number of household members (2). The Northern region, in turn, shows no major changes in the proportion of households headed by women, but reports younger (by 3 years) and less educated household heads (heads with formal education beyond primary school fall by 13%). Southern households show more educated household heads (household heads with formal education beyond primary school increase by 18%), but no major changes in terms of the household head's age and sex (a slight 3% increase of female-headed households).

Table 2.1. Characteristics of agricultural households living in the Andean region (2012), by sub-region

	Andean region	Northern	Central	Southern
Household characteristics				
% household heads who pursued formal education beyond elementary school	33%	19%	35%	38%
Average number of household members	3.3	3.4	3.3	3.1
% households headed by a man	66%	68%	67%	65%
Average age of the head of household	50	48	51	51

Note: Average values are weighted by the number of farm-households in the district.
¥ The information reported in this table refers to districts with valid census information in both years, 1994 and 2012, (i.e., districts that have no farm activity in at least one of the two years are excluded), and valid estimates of crop tolerance index.

In this changing scenario, what are the regional patterns in crop portfolio strategies among Andean farmers? According to the Agricultural Census, 3 out of 4 Northern farmers diversified their crop portfolio in 2012, and that figure rises in the Central and Southern areas to 83% and 90%, respectively. In aggregate, only 16% of Andean farmers concentrate their farm production into monocrops. Crop portfolios are more concentrated in the Northern area than in the Southern and Central areas (Figure 2.5). Crop diversification within the plot (intercropping) is more common in the Northern sub-region, but it is also implemented in Central and Southern areas. Additionally, I find slight changes in crop portfolio tolerance to environmental conditions, increasing in the Central Andes and more variable in the Southern sub-region (Figure 2.5).

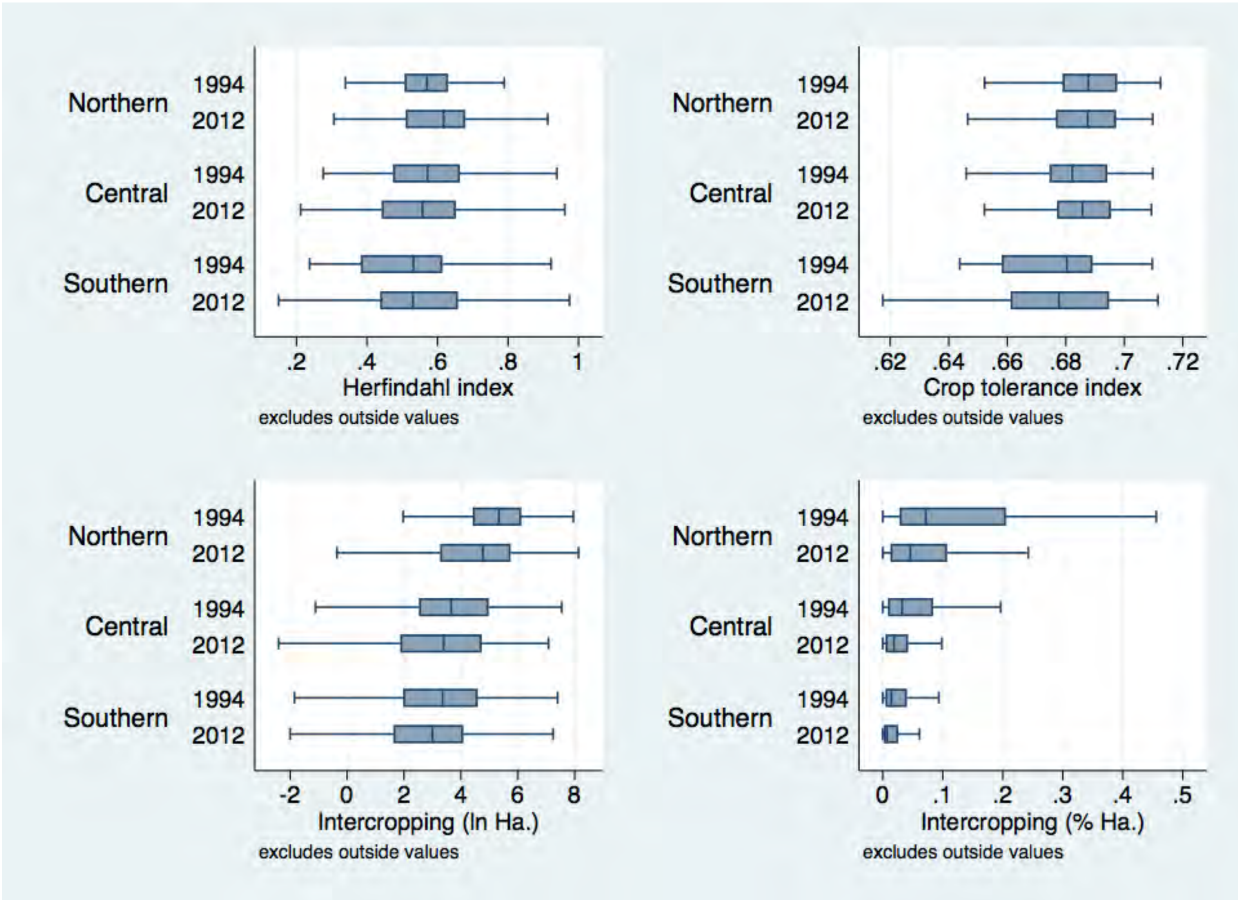


Figure 2.5. Characteristics of Andean farmers' crop portfolio, by sub-region and year.

Note: Average values are weighted by the districts' cultivated area. The information reported in this figure refers to districts with valid census information in both years, 1994 and 2012, (i.e., districts that have no farm activity in at least one of the two years are excluded), and valid estimates of crop tolerance index.

With regards to farmers' production technology (Table 2.2), the most noticeable changes between 1994 and 2012 include an increasing interest in technified—as opposed to gravity—irrigation systems (although gravity systems are still the norm), and an increasing mechanization by using tractors. The amount of increase in technified irrigation systems is greater in the Southern and Central areas (2 to 7% and 1 to 4% of farmers between 1994 and 2012, respectively). Even though adoption of technified irrigation systems is not widespread, given farmers' increased interest, as well as increasing support from public and private agencies, it is likely that these figures have continued to rise. In turn, use of gravity irrigation systems fell in the North and Central sub-regions, especially in the Northern area (13%). This is consistent with the average increase in precipitation during the rainy season in the North. Regarding mechanization of farm production, the proportion of farmers using a tractor increased 10% in the Andean region, especially in the South, where the proportion of farmers using a tractor doubled between 1994 and 2012.

Other decisions key to increasing productivity show less promising progress. The use of certified seeds, which previous studies show improves agricultural productivity, was already low in 1994 (12%) and fell considerably to 6%. The censuses also show less access to technical assistance throughout the region. While 9% of Andean farmers reported receiving technical assistance in 1994, only 3% reported having received it in 2012.

Finally, it is worth noting that in-dwelling access to electricity and water virtually doubled among farm-households in the Andean region between 1994 and 2012, resulting in half of Andean farm-households having access to these two key services by 2012.

Table 2.2. Farm-household decisions about technology and economic activities (2012), by sub-region

	Andean region	Northern	Central	Southern
Technology				
% of farms with technified irrigation system (excludes gravity)	5%	3%	5%	7%
% of farms with some type of irrigation system (gravity, aspersion, drip, or other)	39%	26%	48%	40%
% of farms with cement-lined canals	8%	5%	9%	10%
% of farmers who received technical assistance with agricultural activity	3%	1%	3%	4%
% of farms with mechanized production (tractor use)	29%	10%	20%	55%
% of farms that use certified seeds	6%	6%	8%	5%
Income-generating activities				
% of households that diversify income sources into off-farm activities	42%	36%	44%	44%
% of households that sell some or all of their crops at market	36%	37%	42%	28%

Note: Average values are weighted by the number of farm-households in the district.
[¥] The information reported in this table refers to districts with valid census information in both years, 1994 and 2012, (i.e., districts that have no farm activity in at least one of the two years are excluded), and valid estimates of crop tolerance index.

Given these profiles (demographics, technology, climate, markets access, among other factors), attributing changes in crop portfolio decisions to changes in climate based on descriptive statistics would be highly questionable. As follows, I discuss the estimation results, which control for confounding factors and aim at identifying the role of climate conditions in such decisions.

2.4.2 Estimation results

The first key finding of this study is that an increase in intra-seasonal climate variability (temperature range) affects colder and warmer areas in the Andes differently. It is important to interpret this finding in the context of the Andean region temperate climate (Figure 2.3, Figure 2.4). While a higher exposure of crops to extreme hot events (more extreme and more likely) leads to a higher probability of crop exposure to pests and diseases (though not necessarily to crop loss) throughout the region, in the Andean cooler areas (with minimum temperatures closer to 0˚C) a higher exposure of crops to extreme cold events leads to a higher probability of crop loss. In consequence, it is reasonable to expect that farmers in colder areas respond more systematically to this augmented risk.

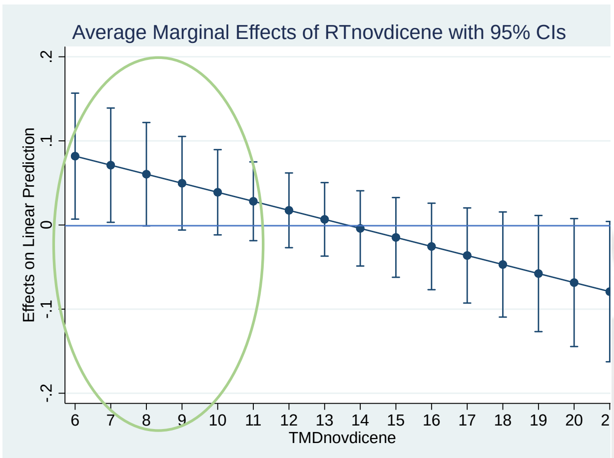
As Figure 2.6 shows, in colder areas, an increase in intra-seasonal climate variability would lead farmers to introduce more tolerant crops in their crop portfolios and reduce the allocation of cultivated land to intercropping. This suggests that, if no interventions take place, in response to higher variability farmers in cold areas would prefer adapting by focusing on selecting crops shown to be more tolerant to environmental diversity, rather than selecting other adaptation alternatives such as diversifying their portfolio (as a means of diversifying the risk of losing some or all of their farm production) or implementing intercropping practices (which, if properly implemented, can help control pests and diseases as well as improve soil fertility)[24].

Though both the Herfindahl and the crop tolerance indices capture changes only at the level of crop species, we know from previous studies that changing to more resilient varieties of the same species is another potentially effective adaptation practice in the face of changes in intra-seasonal climate variability (Lin, 2011). Due to limitations of the census panel data, which provides information on species but not on varieties, these estimates can be interpreted as the lower

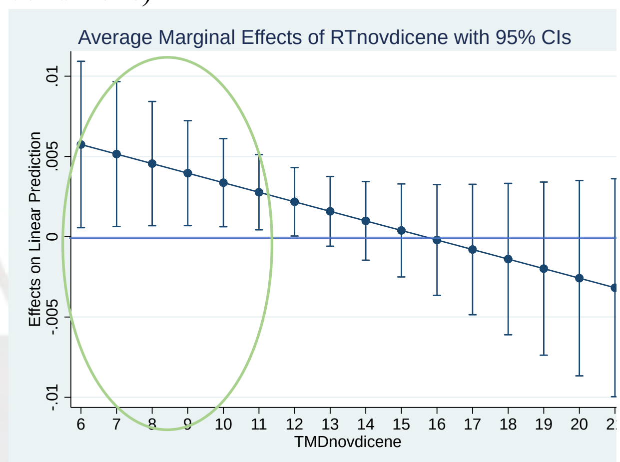
[24] This is especially surprising since Andean farmers have historically coped with climate risk by diversifying their crop portfolios.

bound of the effect of intra-seasonal climate variability on the degree of diversification and on the average tolerance of a crop portfolio[25].

a. Herfindahl Index (concentration of land by crop)



b. Crop tolerance index (district average of crops' tolerance to diverse environmental conditions)



c. Intercropping (cultivated land with companion planting or intercropping (ln))

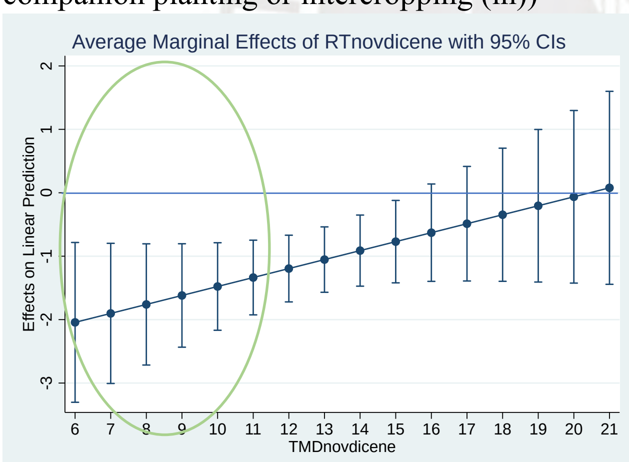


Figure 2.6. Marginal effect of temperature range on crop portfolio decisions, Andean region

Note: Marginal effects for specific average temperature values (*TMDnovdicene*). The range of average temperatures shown in the graphs corresponds to the Andean region's range of average temperatures during the growing trimester, November-January.

[25] Although less than 10% of Andean farmers use certified seeds, in the Southern and Central areas especially, farmers still experiment with new varieties in some of their plots and exchange those seeds with their neighbors. Although less experimentation may be taking place in some areas, the large number of Potato varieties is an emblematic example of this traditional experimentation practice.

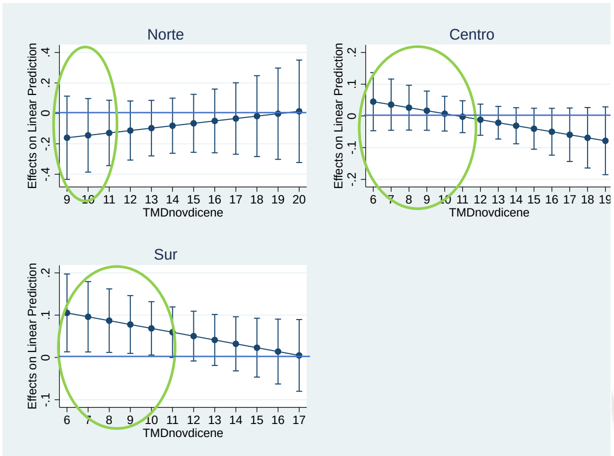
Looking into sub-regions

Given that the Northern, Central, and Southern sub-regions differ in terms of climate conditions (temperature and precipitation) as well as socio-economic and institutional features (market dynamism, the role of external actors, the relative importance of peasant communities as local institutions that regulate the access to land and other natural resources, among others), I investigate potential heterogeneous effects of intra-seasonal climate variability on farmers' decisions across sub-regions.

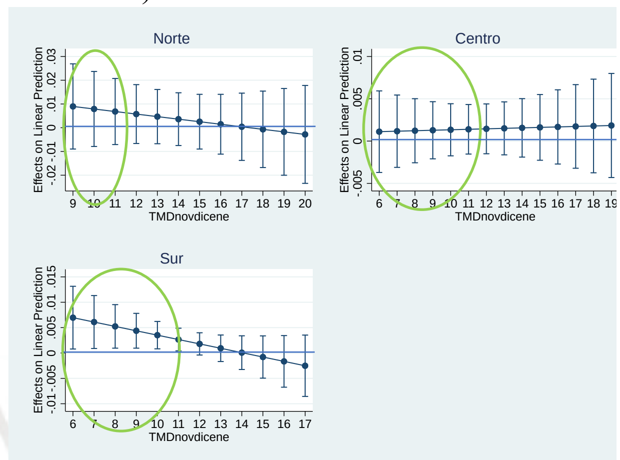
The results confirm that the previous estimates (for the overall Andean region) hide important heterogeneities that help understand households' responses to climate change. Northern districts show no significant effect of an increase in variability. Only 10% of districts face mean temperatures below 12˚C, which according to North-estimates is the threshold under which increasing variability would lead to a decrease in intercropping (Figure 2.7).

In the Central sub-region, where low temperatures are common, the intra-seasonal climate variability effect is no longer significant. This lack of climate variability effect is consistent with a study by Ponce (2018: 31-32) on the effects of intra-seasonal climate variability on non-farm income diversification. That study found that rural households in the Central sub-region respond to an increase in intra-seasonal climate variability by diversifying more into non-farm activities. According to those findings, not only non-farm income (shares and levels) but also working hours devoted to non-farm activities (shares and levels) increase in colder areas (temperature below 12˚C in the growing trimester) as intra-seasonal climate variability increases. It is interesting to note that both Central and Northern sub-regions, which show the least significant effects in this study (except for the marginally significant effects on intercropping in the North), showed the strongest effect for non-farm income.

a. Herfindahl Index (concentration of land by crop)



b. Crop tolerance index (district average of crops' tolerance to diverse environmental conditions)



c. Intercropping (cultivated land with companion planting or intercropping (ln))

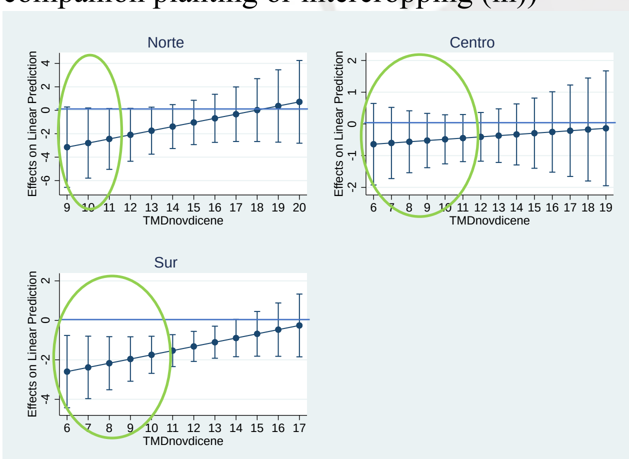


Figure 2.7. Marginal effect of temperature range on crop portfolio decisions, by sub-region.

Marginal effects for specific average temperature values (*TMDnovdicene*).

In turn, Southern farmers respond to an increase in intra-seasonal climate variability by concentrating their crop portfolio into more tolerant crops, and decreasing the land allocated to intercropping (Figure 2.7). This result is also consistent with the study by Ponce (2018)[26] that found no significant effects on non-farm income share and an increase in the number of hours allocated to agricultural activities in the Southern sub-region.

[26] The study presented in this chapter was published Chapter 3 was finished. Ponce (2018) refers to a preliminary version of Chapter 3.

These results raise concern on pressing challenges to farm sustainability in the Andean region, especially in Central and Southern areas, characterized by more indigenous and isolated farm-households.

As previously mentioned, inter-household heterogeneities cannot be captured by district-level data (due to potential aggregation bias or ecological fallacy). An important source of heterogeneity in crop portfolio concentration could be productive assets and capital available to households. Smallholder farmers, lacking physical and financial assets to invest in farming alternatives that both endure higher climate risk and sustain or increase farm income, may respond differently to an increase in climate variability (compared to farmers with more capital, land and better access to markets and information). Previous work suggests a U-shaped relationship between crop concentration and farm self-employment income: very poor farmers with small, low-fertility farmland and low capital may be unable to diversify, but as they get more land and assets they may start growing additional crops, increasing their farm (monetary or no monetary) income. Furthermore, farmers with sufficient land and capital, as well as market access (individual or as part of cooperatives or associations), able to intensify production through better technology and inputs, may be able to concentrate their portfolio into high value commercial crops. In the context of higher climate risk, medium farmers could increase crop portfolio concentration whereas smaller farmers may have to downsize their farm operation (maybe rent some of the land to medium farmers) and keep their crop portfolio smaller but sufficiently diversified (across food crops) to minimize risk while increasing off-farm work. In this case the district effect could be negligible or null, hiding the opposite responses from smallholders and medium farmers. This could be that case of Northern and Central areas, with more dynamic land markets and better access to product, labor and input markets.

In the South, in turn, land markets are less developed (communities hold control over access to land and water in some parts of the sub-region), and geographical isolation of farm-households is higher in average. Therefore, farmers have limited options to rent land, generate wage or off-farm self-employment out of the farm to avoid higher climate risk[27]. Although extra-local networks and complementary assets may help farmers overcome some of these limitations, it is less likely to find systematic differences in farm response involving land concentration as it may be the case in the Central or Northern areas.

[27] In some areas, households need to continue operating their farms to maintain the *comunero* status and keep their right to access farmland.

Regarding other covariates, Table 2.3 shows the estimated coefficients for all variables included in the regressions[28]. It is worth to mention that an increase in mean temperatures lead to heterogeneous responses across Andean districts[29]. While in the Northern districts responses lead to smaller portions of farmland allocated to intercropping, Central districts responses lead to crop portfolios with higher tolerance to environmental diversity, and Southern districts show an average increase in concentration of farms crop portfolios (Herfindahl). When we pool the Andean districts together, we find that an increase in mean temperatures would increase concentration, higher tolerance crop portfolios and smaller land allocation to intercropping (Table 2.4 of Appendix 2).

The average response to increasing mean temperatures in the Northern and Southern areas is troublesome, as it seems to reduce agricultural systems' resilience to environmental stress (such as increasing probability of hot extremes). These results complement the previous discussion on the effects of climate variability on farm sustainability.

The estimation results also inform on farmers characteristics, as well as institutional features and markets access that may play a key role in crop portfolio decisions. Education, associated with work and entrepreneurial skills like those required to respond to environmental challenges and plan crop portfolio strategies, is the factor that seems to play the most consistent role across estimations. It is worth to note that districts in the Northern and Central areas with more educated farmers tend to allocate more land to intercropping. Across districts in the Central Andes, and in most districts of the North[30], no reduction is found as a response to climate variability. In turn, in Southern areas, where an increase in climate variability would lead to a decrease in intercropping farmland, higher education among farmers is not significantly correlated with larger intercropping farmland. These results suggest that more educated farmers can adjust better their ongoing intercropping practices (the right crop mix and inputs) to an increase in variability. This supports the hypothesis that the lack of response to increases in climate variability by increasing intercropping (which reduces incidence of pests and disease and enhances fertility) may be explained by the lack of information and training on new combinations that can thrive in new and more variable (and likely extreme) temperatures.

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[28] Estimation results for the Andean region are presented in Table 2.4 of Appendix 2.
[29] Table 2.5 of the Appendix 2 shows the average marginal effects for temperature mean and temperature range. These estimates include both the linear and the interaction term (evaluated at average values). The sign and significance of the coefficients match those of average marginal effects.
[30] Figure 2.6 shows that an increase in temperature variability leads to a reduction in intercropping farmland in areas with temperatures lower than 12 degrees during the growing season. Less than 10% of the Northern districts follow in this group.

Noteworthy, Central and Southern estimates show that larger membership to peasant communities increases the proportion of farmland allocated to more tolerant crops. Since peasant communities in these sub-regions play a key role as information networks, this result suggests that information and social capital is key to adapt crop portfolio strategies (including intercropping) to those that increase farm resilience to environmental variability.

Finally, although the estimated coefficients on provincial indicators of wider markets dynamics (such as land, off-farm income generating activities, mechanized agriculture, certified seeds and technical assistance) do not provide many insights, their inclusion allows to control for differences in potential market dynamics that may explain part of the district variability in crop portfolios.

Table 2.3. Fixed effects estimations (coefficients, standard errors and significance).

Explanatory variables	(1) Herfindahl index			(2) Crop tolerance index			(3) Intercropping (ln)		
	North	Central	South	North	Central	South	North	Central	South
30-year mean temperature (Nov/Dec/Jan) (ii)	-0.190	0.110	0.276**	0.024	0.014**	0.011	-8.619**	-2.718	-2.560
	(0.351)	(0.131)	(0.131)	(0.027)	(0.007)	(0.007)	(4.246)	(1.797)	(1.997)
30-year temperature range (Nov/Dec/Jan) (i)	-0.302	0.102	**0.160****	0.019	0.001	**0.012***	-6.308	-0.871	**-3.872****
	(0.323)	(0.084)	(0.079)	(0.021)	(0.004)	(0.006)	(4.034)	(1.231)	(1.745)
(i)*(ii)	0.016	-0.009	-0.009	-0.001	0.000	-0.001	0.351	0.039	0.213
	(0.023)	(0.007)	(0.006)	(0.001)	(0.000)	(0.001)	(0.272)	(0.106)	(0.142)
30-year average precipitation (Nov/Dec/Jan)	-0.006*	-0.001	-0.003	-0.000	0.000	0.000	0.145***	-0.030*	-0.022
	(0.004)	(0.001)	(0.003)	(0.000)	(0.000)	(0.000)	(0.046)	(0.017)	(0.042)
% of farms with an irrigation system	-0.310***	-0.081	-0.056	0.002	0.010	-0.002	2.691	2.457*	0.081
(either gravity, aspersion, dripping, or other)	(0.109)	(0.075)	(0.112)	(0.011)	(0.006)	(0.004)	(1.776)	(1.302)	(1.592)
Dummy of year (1=2012)	0.031	0.115*	-0.267***	0.013*	-0.009***	-0.001	-3.929***	-0.971	-0.934
	(0.095)	(0.064)	(0.074)	(0.008)	(0.003)	(0.004)	(1.163)	(0.725)	(1.447)
% of farm-households headed by a man	0.641***	0.092	-0.377*	0.006	0.004	-0.029***	-2.850	-6.135**	-1.416
	(0.217)	(0.167)	(0.193)	(0.015)	(0.009)	(0.010)	(2.253)	(2.418)	(2.773)
Average age of farm-household heads	0.011	-0.013**	0.020***	-0.000	0.000*	-0.000	0.047	0.071	-0.057
	(0.007)	(0.006)	(0.006)	(0.001)	(0.000)	(0.000)	(0.077)	(0.059)	(0.097)
Average number of farm-household members	-0.042	-0.026	-0.027	0.001	0.000	0.001	-0.382	-0.096	0.602
	(0.028)	(0.025)	(0.026)	(0.002)	(0.001)	(0.001)	(0.330)	(0.323)	(0.433)
% of farm-households headed by a person who	0.616***	-0.387**	0.571***	-0.015	0.021***	-0.011	8.091**	10.959***	5.347
pursued formal education beyond elementary school	(0.231)	(0.188)	(0.208)	(0.019)	(0.008)	(0.009)	(3.209)	(2.896)	(3.689)
(> 6 years)									
% of farms with access to at least one concrete-lined	0.244	0.160**	0.001	-0.002	-0.002	-0.006**	-2.325	-1.910**	2.360**
irrigation canal	(0.235)	(0.077)	(0.089)	(0.018)	(0.004)	(0.003)	(3.508)	(0.879)	(1.055)
(Cont..)									

(continues in the next page…)

Explanatory variables	(1) Herfindahl index			(2) Crop tolerance index			(3) Intercropping (ln)		
	North	Central	South	North	Central	South	North	Central	South
(.. Cont.)									
Land Gini coefficient (equivalent hectares)	-0.471**	-0.157	-0.408***	-0.017	0.002	0.017***	2.402	-4.739***	-1.466
(at province level)	(0.236)	(0.112)	(0.127)	(0.017)	(0.006)	(0.006)	(2.652)	(1.464)	(1.899)
% of farmers that diversify into off-farm activities	0.117	0.045	0.108	-0.031**	0.008	-0.010	1.988	-2.146	2.955*
(at province level)	(0.188)	(0.134)	(0.109)	(0.015)	(0.006)	(0.007)	(2.191)	(1.873)	(1.695)
% of cultivated area with mechanized agriculture	-0.005	0.219**	0.146	-0.005	-0.011*	0.012***	0.817	-1.384	-0.159
(tractor) (at province level)	(0.234)	(0.086)	(0.097)	(0.016)	(0.005)	(0.004)	(2.331)	(1.092)	(1.345)
% of farms using certified seeds	-0.721*	0.235	0.243	0.011	-0.017	-0.006	0.757	-4.327*	-8.635***
(at province level)	(0.404)	(0.251)	(0.194)	(0.028)	(0.011)	(0.010)	(5.088)	(2.499)	(2.733)
% of farms that received technical assistance -	-0.424	0.630	-0.235	0.024	-0.022	0.021**	-9.320	-2.792	-2.473
(at province level)	(0.691)	(0.414)	(0.168)	(0.048)	(0.021)	(0.011)	(6.499)	(4.748)	(3.200)
% of farms managed by a member of a Peasant	0.045	0.014	-0.022	0.010	0.007**	0.005**	-1.708	0.750	-1.148
Community (who manages the land as a *comunero*,	(0.195)	(0.054)	(0.067)	(0.014)	(0.003)	(0.003)	(1.803)	(0.703)	(0.810)
instead of as the land owner, lessee, or occupant) - (at									
province level)									
Constant	4.205	0.253	-3.383*	0.365	0.463***	0.525***	130.597*	45.460**	55.370*
	(5.477)	(1.655)	(1.783)	(0.409)	(0.091)	(0.090)	(66.951)	(22.833)	(28.232)
R-squared	0.319	0.149	0.323	0.156	0.152	0.283	0.455	0.262	0.255
Number of districts æ	191	620	357	186	616	356	191	610	347
Hausman specification test									
Chi2(17)	54.07	81.57	49.96	27.89	66.49	275.28	52.6	50.1	45.74
Prob>Chi2	0.00	0.00	0.00	0.0463	0.000	0.000	0.000	0.000	0.0002

Note. District observations weighted by corresponding cultivated area. Robust standard errors in parentheses (adjusted to account for potential heteroscedasticity), *** p<0.01, ** p<0.05, * p<0.1.
æ The list of districts in 1994 and 2012 was made compatible (new districts were collapsed into the old districts, for example), in order to have homogeneous territorial units for both years.

Robustness

As previously mentioned, given that census operations do not collect in-depth information, for an accurate estimation it is crucial to choose a model specification that accounts for as many potential sources of bias as possible. To identify the effect of an increase in intra-seasonal climate variability on crop diversification strategies, it is necessary to control for other confounding factors that could influence households' decisions. The Hausman specification tests, performed on the estimated models for all three crop portfolio decisions analyzed in this study, proved that random effects estimates would be biased due to the correlation between observed time-variant covariates and unobserved time-invariant factors. This is true not only about the Andean region's estimates, but also about each of the sub-regional estimates. Thus, besides adjusting for time-variant observables, like those reported in Table 2.1 and Table 2.2, controlling for time-invariant (or at least medium-time-invariant) factors proves to be key to the estimation strategy.

Finally, all estimations weighted each district by its cultivated area, and adjusted the parameters' standard errors to account for heteroscedasticity.

2.5 Final remarks

This study finds that, ceteris paribus, an increase in intra-seasonal climate variability has a heterogeneous effect on crop portfolio decisions. Given the environmental (topographic and climatic) diversity of the Andean region, the study explores the heterogeneous effects of intra-seasonal climate variability across the temperature gradient. Assuming that no interventions take place, the findings show that an increase in intra-seasonal climate variability in cold areas (with mean temperatures below 11˚C during the growing season) would lead farmers to concentrate their crop portfolios into crops that tolerate a broader range of climate conditions (more tolerant crops), while reducing the practice of intercropping (multi-cropping agronomic practice that tends to favor soil fertility and pest and disease control). This effect is statistically significant in the Southern region, which is characterized by high altitudes, more indigenous and isolated population and more extreme temperatures.

These results highlight the need to help Andean farmers reach timely and effective information, inputs, and technical assistance to adapt their current intercropping practices to the changing environmental conditions. Detailed information is required to transition to more detailed policy recommendations. This line of study may complement field assessments of specific local climate risks and vulnerabilities required to develop effective programs to assist with locally-specific farming issues. In particular, gathering information on crop varieties in surveys and the Agrarian Census would allow for a more precise estimation of crops' (or varieties') resilience to environmental variability. This information would also inform public policy on priorities for advancing a more widespread use of certified seeds, as well as other interventions oriented toward improving the productivity of Andean farms.

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2.7 Appendices

2.7.1 Appendix 1. Measuring crop tolerance with a co-occurrence index (summarizing the methodological explanation presented by (Ponce & Arnillas, 2018))

The niche of a species, including crops, is the set of environmental conditions where a species or crop can thrive (Hutchinson, 1978). The more tolerant a species is, the more environmental conditions it can support. The species niche encompasses multiple axes, and measuring the niche characteristics can be biased by the set of environmental axes used (Fridley, Vandermast, Kuppinger, Manthey, & Peet, 2007). Because very similar environmental axes affect all the species, it is possible to measure a species niche using other species presence or absence when these species have been observed in multiple sites: When a focal species is tolerant to a narrow set of conditions, the other species able to thrive in those conditions will be a consistent set of species that repeat itself from one site to another. In contrast, when the focal species is tolerant to a wide set of conditions its companion species will likely change from site to site (Fridley et al., 2007). Therefore, the tolerance of a crop can be compared to the tolerance of another one by measuring the magnitude of change in the crops that co-occur with the focal crop along several sites.

Beta-diversity metrics estimate the magnitude of change among sets of species, and some can be adapted to measure species tolerance using co-occurrences. Co-occurrence tolerance metrics based on beta-diversity metrics use randomizations to account for the fact that some species are more frequent than others and that some sites support more species than others (Fridley et al., 2007). This study uses the crop tolerance estimates obtained by (Ponce & Arnillas, 2018) using the multiple-site Simpson index (Manthey & Fridley, 2009) proposed as a beta-diversity metric by Baselga, Jiménez-Valverde, and Niccolini (2007: 643).

To measure the *k* crop's tolerance (θ^k), (Ponce & Arnillas, 2018)first defined M^k as

$$M^k = \frac{\sum_i (S_i) - S_T}{\left[\sum_{i<j} \min\left(b_{ij}, b_{ji}\right)\right] + \left[\sum_i (S_i) - S_T\right]}$$

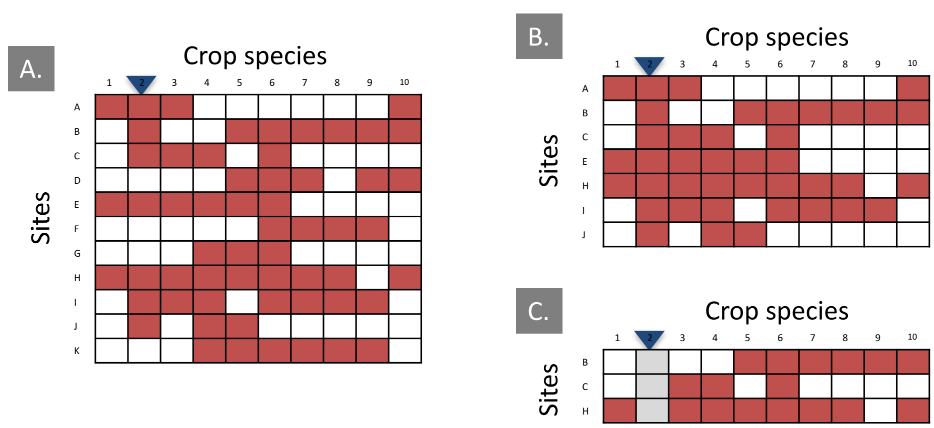
where i is a site where the focal crop k occur, S_i is the number of crop species in site i, S_T is the total number of crop species, and b_{ij} is the amount of crop species that grow in site i but do not grow in site j. As in (Ponce & Arnillas, 2018), in this study a site is the same as a district.

To avoid biases in the index caused by different species abundances (Ponce & Arnillas, 2018) focused on crops present in at least 20 of the 1732 sites (districts). For each of these crops they randomly sampled 10 sites and estimated M^k . The sampling was repeated 500 times and the crop tolerance was defined as the average of all these values:

$$\theta^k = 1 - \sum_{s=1}^{500} (M^k)$$

where θ^k ranges from 0 (low tolerance to diverse environmental conditions) to 1 (higher tolerance).

Diagram 1. Example of the θ^k_{sim} estimation procedure with a minimum threshold of 6 sites (instead of 20). (Reproduced with permission from (Ponce & Arnillas, 2018))



For each crop species found in more than x=6 sites (Fig A):

a) Select the sites where the species is present (Fig B).
b) Choose x/2=3 sites (districts) randomly (Fig C).
c) Measure similarity between sites (M_{sim}) using the other crop species only.
d) Repeat steps (b) and (c) n=500 times.
e) Compute the average of the n=500 results obtained in (c), and substract that average from 1.

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2.7.2 Appendix 2. Complementary Tables and Figures.

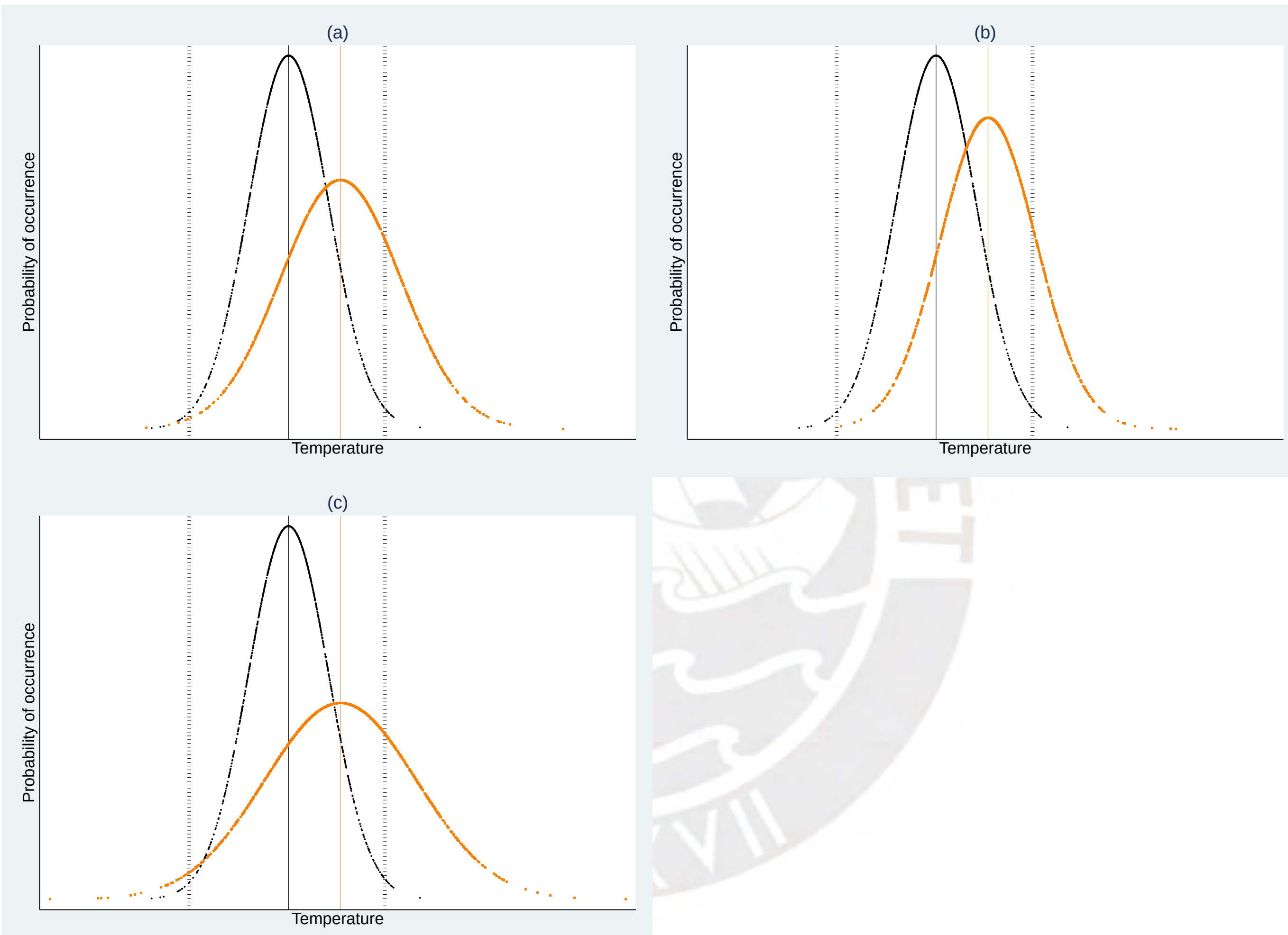
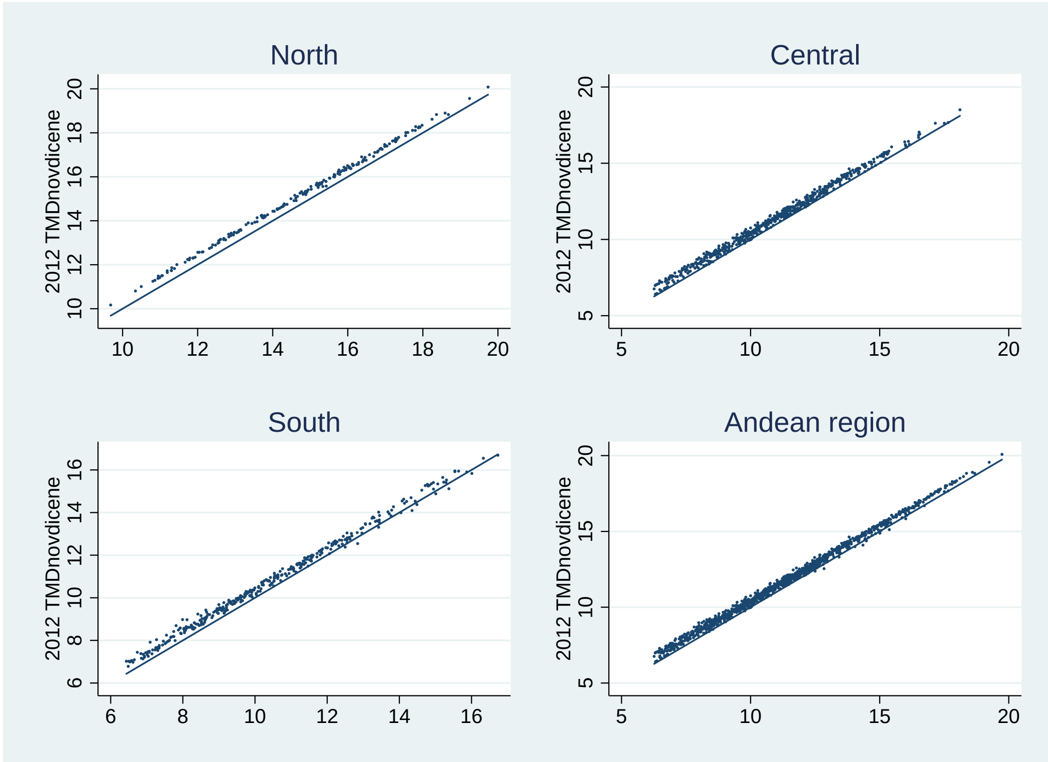


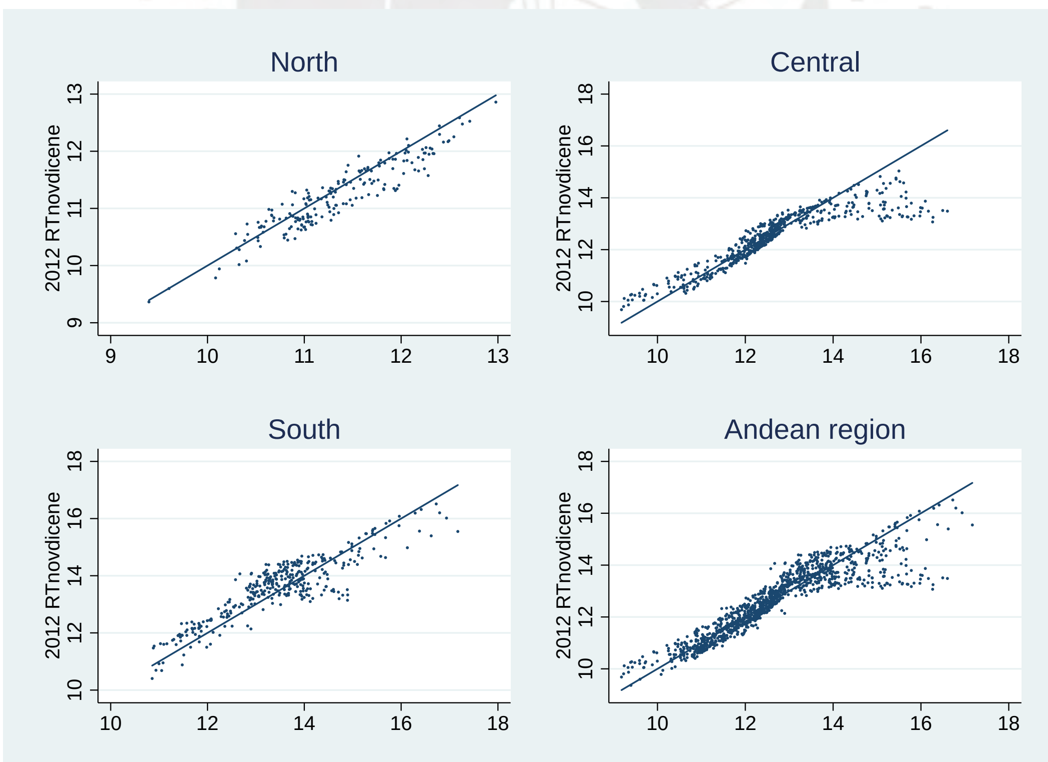
Figure 2.8 Schematics showing three scenarios consistent with a simultaneous increase in mean temperature and temperature variability.

Three scenarios consistent with a simultaneous increase in mean temperature and temperature variability parameters: (a) an increase in variability that entails no change in the lowest tail, that reduces the probability of having cold temperatures and increases the probability of hot weather, including new record hot weather, (b) a similar increase in variability but with an upwards shift of the lowest tail, and (c) an increase in variability that entails an increase in probability of hot and cold extreme weather.

(a) Mean temperatures

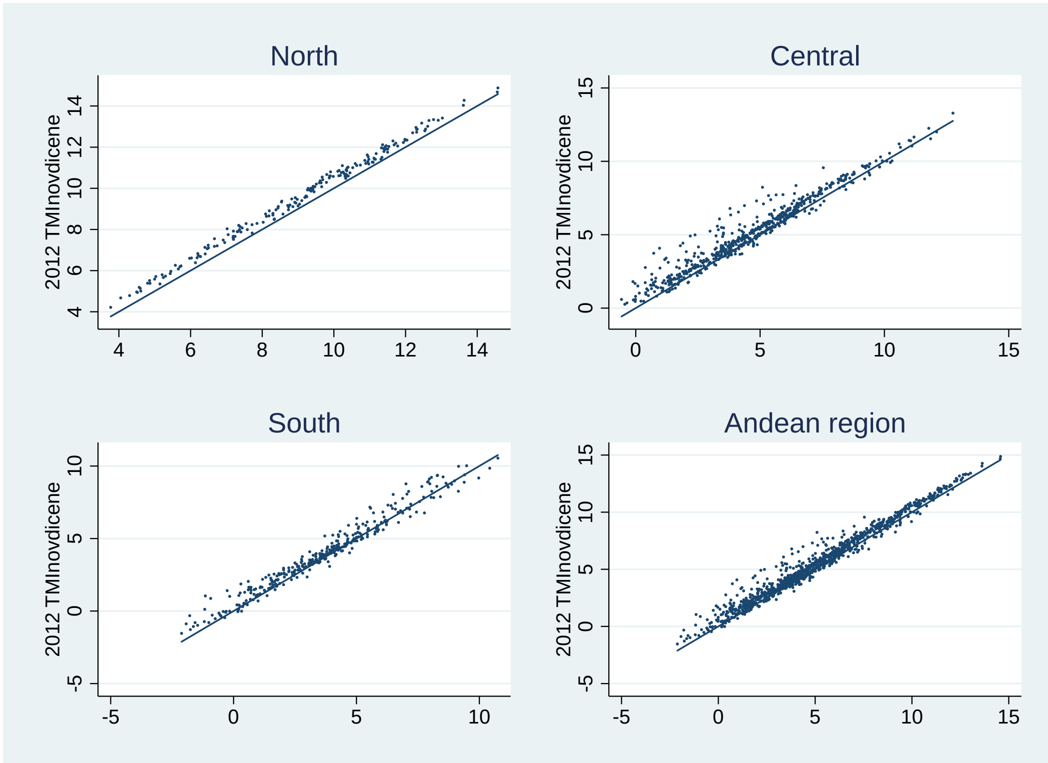


(b) Temperature range (proxy for climate variability)



(continues in the next page…)

(c) Minimum temperatures



(d) Maximum temperatures

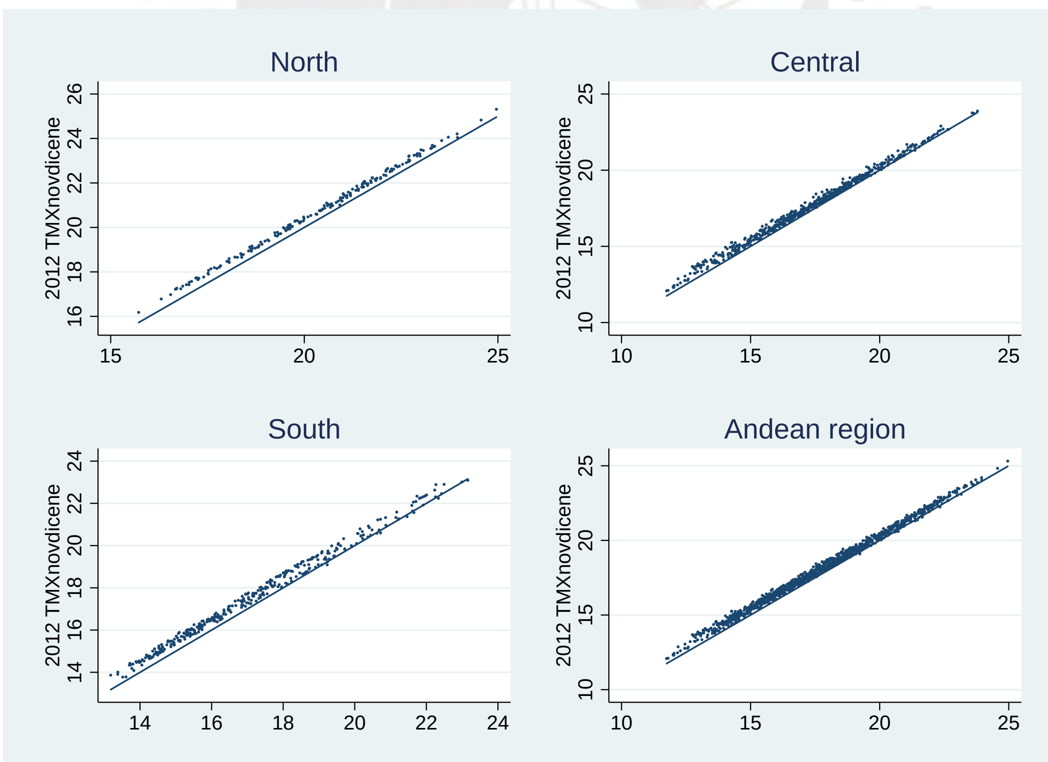


Figure 2.9. Climate Parameters for the Andean region (November-January trimester, direct

estimates).

Periods 1964-1994 (horizontal axis) and 1982-2012 (vertical axis). The 45˚ line represents no change in the climate indicator. Source: Based on district-level climate indicators estimated by Ponce, Arnillas, and Escobal (2015).

Table 2.4. Fixed effects model coefficients, Andean region.

Variables	Herfindahl	Crop tolerance index	Intercropping (ln)
30-year average temperature (Nov/Dec/Jan) (ii)	0.249***	-0.190	0.110
	(0.089)	(0.351)	(0.131)
30-year temperature range (Nov/Dec/Jan) (i)	0.092	-0.302	0.102
	(0.102)	(0.323)	(0.084)
(i)*(ii)	-0.011**	0.016	-0.009
	(0.004)	(0.023)	(0.007)
(i)*Dummy for Northern Andes	0.000		
	(0.000)		
(i)*Dummy for Central Andes	0.045		
	(0.068)		
(i)*Dummy for Southern Andes	0.101		
	(0.072)		
30-year average precipitation (Nov/Dec/Jan)	-0.001	-0.006*	-0.001
	(0.001)	(0.004)	(0.001)
% of farms with an irrigation system (either gravity, aspersion, dripping, or other)	-0.097*	-0.310***	-0.081
	(0.053)	(0.109)	(0.075)
Dummy of year (1=2012)	-0.004	0.031	0.115*
	(0.039)	(0.095)	(0.064)
% of farm-households headed by a man (district)	0.101	0.641***	0.092
	(0.105)	(0.217)	(0.167)
Average age of farm-household heads (district)	-0.001	0.011	-0.013**
	(0.003)	(0.007)	(0.006)
Average number of farm-household members (district)	-0.031**	-0.042	-0.026
	(0.015)	(0.028)	(0.025)
% of farm-households headed by a person who pursued formal education beyond elementary school (> 6 years) (district)	-0.096	0.616***	-0.387**
	(0.120)	(0.231)	(0.188)
% of farms with access to at least one concrete-lined irrigation canal (district)	0.089	0.244	0.160**
	(0.058)	(0.235)	(0.077)
Land Gini coefficient (equivalent hectares) - Province	-0.402***	-0.471**	-0.157
	(0.069)	(0.236)	(0.112)

Variables	Herfindahl	Crop tolerance index	Intercropping (ln)
% of farmers that diversify into non-farm activities - Province	0.045	0.117	0.045
	(0.062)	(0.188)	(0.134)
% of cultivated area with mechanized agriculture (tractor) - Province	0.141**	-0.005	0.219**
	(0.064)	(0.234)	(0.086)
% of farms using certified seeds - Province	0.089	-0.721*	0.235
	(0.131)	(0.404)	(0.251)
% of farms that received technical assistance - Province	-0.065	-0.424	0.630
	(0.178)	(0.691)	(0.414)
% of farms managed by a member of a Peasant Community (who manages the land as a *comunero*, instead of as the land owner, lessee, or occupant) - Province	0.030	0.045	0.014
	(0.043)	(0.195)	(0.054)
Constant	-2.133*	4.205	0.253
	(1.247)	(5.477)	(1.655)
R-squared	0.154	0.319	0.149
Number of districts [æ]	1,168	191	620
Hausman specification test			
Chi2(19)	115.14	54.07	81.57
Prob>chi2	0.00	0.00	0.00

Fixed effects estimates: District observations weighted by corresponding cultivated area. Robust standard errors in parentheses (adjusted to account for potential heteroscedasticity), *** p<0.01, ** p<0.05, * p<0.1.
æ The list of districts in 1994 and 2012 was made compatible (new districts were collapsed into the old districts, for example), in order to have homogeneous territorial units for both years.

Table 2.5. Average marginal effect of climate conditions on crop portfolio decisions (only statistically significant effects are shown).

	Herfindahl index (degree of crop concentration)	Crop tolerance index (tolerance to environmental diversity)	Cultivated land allocated to intercropping
Andean region			
Intra-seasonal climate variability		0.002 **	-1.2***
Average temperature	.1 **	0.006*	-2.1**
% farmers with irrigation system	-.1*		1.9**
Northern Andes			
Intra-seasonal climate variability			
Average temperature			-4.6 "
Central Andes			
Intra-seasonal climate variability			-2.2*
Average temperature		0.15***	-0.3*
Southern Andes			
Intra-seasonal climate variability	0.06**	0.003**	-1.6***
Average temperature	0.15*		

*** p<0.01, ** p<0.05, * p<0.1. Marginally significant estimate: " pvalue 0.135.

3 Revisiting the determinants of non-farm labor income in the Peruvian Andes: the role of intra-seasonal climate variability and widespread family networks [31]

Abstract

As previous literature shows, non-farm income represents up to 50 percent of rural household income in developing countries. Mostly due to lack of representative information on climate and family networks, two key factors have been excluded in previous studies on income diversification: (i) the role of intra-seasonal climate variability (affected by climate change), and (ii) the role of family networks located in distant areas (increasingly important given population mobility due to internal conflicts and improved roads and communications). This study analyzes the role of these factors on non-farm working hours and non-farm income shares in the Peruvian Andes. Controlling for other assets and environmental conditions, the study finds that households with distant, strong networks diversify more into non-farm activities. Increases in intra-seasonal climate variability (measured by temperature range during the main crop growing season) have heterogeneous effects across subregions. While we find no direct effect among Southern households (more isolated and indigenous), households in the cooler areas of the Central and Northern Andes (below 13˚C during the crop growing season) tend to increase non-farm income as climate variability increases. The study suggests that distant, strong ties facilitate non-farm opportunities to households facing increasing temperature variability in the Central and Southern Andes.

[31] This study is under review at the Journal of Development Studies. A previous version of this chapter was uploaded online as a progress report, at http://www.grade.org.pe/wp-content/uploads/GRADEai34.pdf.

3.1 Introduction

Non-farm income sources are increasingly important, representing between one third and one half of rural household income in developing countries (Reardon et al. 2007)[32]. Previous studies suggest that non-farm income can help reduce poverty and strengthen investment in agricultural activities; however, evidence shows that this positive linkage between non-farm activities and poverty reduction depends on market dynamism (Reardon, Berdegué, & Escobar 2001; Lanjouw 2007). The literature also shows the important role that education and access to infrastructure and markets, as well as the elimination of market failures, have in facilitating access to non-farm high-paying jobs for rural households in the developing world (Himanshu et al. 2013, Lanjouw & Murgai 2009, Reardon et al. 2007, de Janvry & Sadoulet 2001 among others). Although these studies have extensively analyzed the determinants of non-farm income, two common features in many developing countries have not yet been integrated in the analysis: (i) the role of intra-seasonal climate variability (affected by climate change)[33], and (ii) the role of family networks located in distant areas (increasingly important given population displacement during the internal conflict and increasing road and communications connectivity). This study, focused on Peruvian Andean rural households, aims to contribute to this pending agenda.

The Peruvian Andean region is particularly interesting for two reasons. First, according to the IPCC (2014a), the Andean region has been severely affected by climate change, mostly due to the increase in temperature—accelerating the glacier retreat—and the heterogeneous changing patterns in precipitation. Although Andean farmers have historically managed to cope with climate variability, climate change has intensified and made less predictable the already variable conditions that Andean farmers face during the crop growing season (Vergara 2012, Postigo 2012, Valdivia et al. 2010, Escobal & Ponce 2010, among others). Second, the internal conflict that took place in Peru during the eighties and nineties affected the Andean and indigenous population (most of them farmers) disproportionately more than other groups and caused population displacement

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[32] Hazell, Haggblade, and Reardon (2007: 84) compile evidence from several studies and show increases of rural non-farm income shares among farm households from 17% to 39% between 1978-80 to 1997 in China, from 22% to 84% between 1950 and 1987 in Japan, from 18% to 46% between 1971 to 1991 in South Korea, from 45% to 78% between 1970 and 1987 in Taiwan, and 35% to 46% between 1976 and 1986 in Thailand.

[33] According to the IPCC (2014b), climate refers to "the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation, and wind." Here, we study intra-seasonal climate variability, which is *proxied* by the 30-year average temperature range, calculated as the difference between the average maximum and the average minimum temperatures estimated for a particular trimester.

across the country (some of whom returned after the end of the war). Furthermore, the greater connectivity achieved in the last three decades has enhanced population mobility, both permanent and seasonal, and the consolidation of intermediate cities has fostered rural-urban socio-economic linkages (Llona, Ramirez, & Zolezzi 2004; Ponce 2010). As a result, 3 out of 10 Andean rural households in Peru report having a sibling or parent of the household's head or spouse living in a different province[34] (5 out of 10 if emigrant household children are included).

This study investigates the role of intra-seasonal climate variability (difference between 30-year-average maximum and minimum temperatures during the crop growing season) and spatially distant family networks in the relative importance of non-farm income in the rural Andes. Whereas an increase in climate variability entails an increase in risk and vulnerability for farm activities, family networks located in distant regions (that do not share local climate or market shocks) may become a key asset for managing risk and fostering income opportunities (as long as they convey information and opportunities that are not available through local networks). Given the market imperfections that are common in developing rural areas—especially those related to climate risk management—, explicit consideration of both factors is key to understanding rural households' diversification strategies amid –ongoing— climate change and rural-urban transformations.

Two household economic outcomes summarize the relative importance of non-farm income sources in this study: the non-farm labor income share (the proportion of labor income earned from non-farm activities), and the non-farm labor share (the proportion of household working hours allocated to non-farm activities). As usual in this literature, non-farm activities refer to activities other than agriculture -which includes the production of crops, livestock husbandry, aquaculture, woodlot production, hunting, fishing, and forestry- (Haggblade, Hazell, & Reardon 2007; Dirven 2004). In the Andean region, the crop production and livestock husbandry are the main components of agricultural activities. Non-farm sources of income include both wage work and self-employment.

Although, as mentioned before, previous literature has discussed potential mechanisms linking climate change and social capital to rural household decisions, the lack of statistically representative information on local patterns of climate change, especially intra-seasonal climate variability, and on spatially distant family networks has made impossible to analyze the actual response of rural households to both changing factors. The analysis in this study takes advantage

[34] Peru is divided into three political-administrative levels, consisting of 25 departments, 196 provinces, and 1,867 districts.

of the largest survey performed in Peru for rural areas, representative of rural households at the province level: the Provincial Survey of Rural Households (EPHR, for its initials in Spanish). Despite the limitations that a cross-sectional analysis usually entails, this survey is the first one to provide rural household information about both income-generating strategies and the location of direct family networks across the country. Furthermore, given the strong representativeness of this survey, it allows for not only the estimation of province-level productivity measures (rarely available) but also, more importantly, of heterogeneous parameters for domains that show different climate patterns and socio-economic dynamics (North, Central, and South domains). The statistical information from EPHR is complemented by climate indicators at the district level, estimated by Ponce, Arnillas, and Escobal (2015). These estimates include the district's 30-year average of temperature range—a proxy for intra-seasonal climate variability—, mean temperature and precipitation. Since these estimates were intended to help analyze farm households' strategies and decisions, they are constrained to the climate conditions of areas under 4,800 m.a.s.l.[35], above which agriculture is biologically unviable (Ponce, Arnillas and Escobal 2015). Finally, complementary information about climate shocks in the last season as well as socio-political and economic features at household and province level was used to account for environmental conditions that may affect households' decisions on income diversification strategies.

The document is organized in four sections, including this one. The following section presents a literature review about the determinants of non-farm income and rural households' diversification strategies, with emphasis on the role of climate risks and vulnerabilities. In addition, given the scarce literature on the role of spatially distant family networks in rural households' diversification strategies (besides their role as migration capital), we discuss the literature on the role of strong and weak ties in economic outcomes and link it to rural households' income diversification decisions. Section 3 explains the data and methods used in the analysis, and section 4 discusses the results.

3.2 Rural households' income diversification into non-farm activities in the developing world, what we know so far.

There is a vast literature on the increasing importance of non-farm income and the role it plays in reducing rural poverty in various developing countries (Reardon, Berdegué and Escobar 2001;

[35] Meters above sea level.

Reardon et al. 2007). Based on 54 country studies published in the 1990s and 2000s, Reardon et al. (2007) argue that non-farm income accounts for 47%, 34%, and 51% of rural income in Latin America, Africa, and Asia, respectively. One of these studies, led by Escobal (2001), focuses on Peru. Escobal (2001: 502) shows that non-farm income represented 47% of labor income in the rural Peruvian Andes region in 1997 (42% and 5% from self-employment and wage employment sources, respectively).

Reardon et al. (2007) emphasize that the factors leading rural households to diversify into non-farm activities may differ substantially across income groups. While some households diversify off-farm to accumulate capital, perhaps for reinvestment in agricultural technology, and to grow financially (pull factors), others diversify to cope with poverty and deprivation, aiming to reduce their vulnerability to the risks and shocks usually involved in agricultural activities (push factors). In some cases, like the *ejidos* in Mexico, farmers with small land holdings diversify more than those with larger land to complement their low farm income, due to the absence of land markets (de Janvry & Sadoulet 2001).

Building on previous studies, Reardon et al. (2007) classify the determinants of income diversification into non-farm activities in three groups: relative prices of outputs and inputs associated with each activity (incentive levels), relative risks involved in each activity including climatic and market risks (instability of incentives), and assets available to the household, including human, social, financial, organizational, and physical (capacity variables). Escobal (2001) emphasizes that, in the absence of efficient markets, individual and institutional constraints can further affect diversification strategies. Reardon et al. (2007) also highlight the importance of local market dynamism. A growing sector in the local environment—whether agriculture, mining, or tourism—drives up demand for non-farm goods and services, increasing wage employment and self-employment opportunities.

To identify the mechanisms through which climate and spatially distant family ties may affect rural households' decisions to diversify, the following paragraphs synthesize the main findings of previous studies.

3.2.1 Effect of climate on rural households' economic outcomes

Climate conditions are arguably the main source of risk for agricultural activities in the Andean region. They do not only affect yields and productivity but may affect local (and sometimes regional) prices as well. Several studies argue that diversifying into non-farm activities is a strategy for (*ex ante*) managing climate risk and (*ex post*) coping with climate shocks (Reardon et al. 2007, Mertz et al. 2011, Dasgupta et al. 2014). A complementary strategy for managing climate risks in the Andean region is diversification of the farm's crop portfolio (Lin 2011, Valdivia et al. 2010, Earls 1991, Figueroa 1989, Ponce 2020).

Reardon et al. (2007) propose a conceptual framework for understanding the mechanisms underlying the push factors that induce poor households to diversify into non-farm activities. They point out to four push factors associated with climate conditions and risks. First, the seasonal nature of agricultural activities is characterized by periods with very low farm activity. When farm income cannot cover the household's needs for the whole year, households need to allocate their remaining working time and resources to pursue other income-generating activities to complement farm income. Second, unexpected extreme climatic events like droughts or hail may severely affect farm income and force households to transitorily embark on off-farm[36] activities to compensate for the loss of on-farm income (such as farm wage employment in a different region unaffected by the climate shock, or non-farm activities). Third, less transitory changes in climate conditions, or other key factors such as soil quality or market conditions, may affect negatively farm activities and call for a more permanent change in income-generating strategies, away from agriculture self-employment. Finally, a fourth push factor, associated with the second one, is that credit or insurance market failures push households to find alternative ways to self-insure against climate shocks or fund purchases of farm inputs. The authors argue that weak land and labor markets may also induce households to diversify into non-farm activities. These mechanisms are taken into consideration in the estimation strategy presented in Section 3.

Household perception of long-term climate trends as well as the associated expectations on weather conditions for the following crop growing period are key for decision making about resource allocation and investment across farm and non-farm activities. The potential mismatch between household expectations and actual conditions -taking place after harvest and market transactions- affects final economic outcomes (household farm and non-farm income and working hours). Several case studies have been conducted to understand rural households' perceptions of climate change and its effects on water sources and extreme events affecting their crops and pastures. Claverias (2000) contrasts farmers' climate predictions based on local practical

[36] On-farm activities refer to farm activities undertaken on the household's own farm. In contrast, off-farm activities include farm wage employment, and non-farm wage and self-employment. The present study is focused on the farm/non-farm divide (farm: agricultural wage and self-employment; non-farm: non-agricultural wage and self-employment).

knowledge (32 farmers from four communities in Puno, Southern Andes) with the actual conditions that occurred during the agricultural years 1989-90 and 1990-91. He points out the need to complement local practical knowledge with scientific knowledge about climate conditions when designing and implementing interventions to enhance productivity and economic opportunities for Andean farmers. The author also highlights that predictions differ between farmers, as do the sources upon which they base their predictions (plants, animal behavior, astronomy, and/or meteorology), depending on their age and experience in the agricultural sector, among other factors. Other studies focus on within-farm adaptive practices as a response to Andean households' perceptions of climate change (Young & Lipton 2006, Lin 2011). Vergara (2012) analyzes adaptive practices and households' perceptions of climate change in a community in the Conchucos Valley, in Ancash (Central Andes). Vergara (2012) reports that local knowledge, based on the observation of plants, animals, and astronomy, is still applied in this community. She highlights, however, that farmers in the community argue that local knowledge is not as effective and accurate as it used to be. According to farmers, rain timing has become unpredictable, making more difficult to establish the optimal time to sow and harvest. Among the consequences of the temperature increase, the more frequent occurrence of pests and diseases affects soil fertility and pasture quality, and frosts and droughts have reduced the production of native crops (Vergara 2012). Based on census data, Ponce (2020) finds evidence of heterogeneous farmers response to climate variability across the Peruvian Andes; while households in the Northern and Central Andes, more connected with cities and regional markets, show no change in farm crop portfolios, households in the South increase crop concentration in favor of crops that tolerate a wider range of environmental conditions (i.e. have a broader niche breadth). Given that traditionally Andean farmers use diversified crop portfolios to minimize climate risk, this response seem troublesome and one that could be explained by their lack of assets and technical support required to implement innovative strategies to cope with increasing climate risks. The present study complements those findings by analyzing income diversification strategies undertaken by rural Andean dwellers.

It is important to highlight the difference between two terms used in this study, weather and climate. Whereas weather refers to short-term atmosphere conditions (on a daily basis, for instance)[37], the term climate refers to atmosphere conditions over longer periods of time (usually 30-year periods). More importantly, climate parameters usually refer to mean and variability features of the long-term distribution of climatic conditions in a specific area, whereas weather usually refers to the specific realization of such distribution in a short period of time. Since both

[37] There is a vast literature on the effects of weather shocks on household outcomes (Dell, Jones, & Olken 2014).

expectations on future climate conditions and actual climate conditions are key to explain households economic outcomes such as farm and non-farm income and working hours[38], we need to consider not only parameters of local climate distribution (which influence household expectations and average climate realizations), but also recent shocks and household characteristics that may explain heterogeneous household expectations and responses (such as age and experience, as explained by Claverias (2000)). In the following section we describe the information on climate we use to account for these factors: climate conditions affecting current expectations (30-year average temperature range, mean temperature and mean precipitation and change in those conditions in the last two decades), weather shocks in the previous crop growing season; and households characteristics affecting differences in individual climate expectations.

3.2.2 The role of weak and strong ties in economic outcomes

The importance of social networks for economic outcomes and behavior has been widely discussed and documented (see surveys by Ioannides & Loury 2004 and Jackson et al. 2017 from the economics literature; and Granovetter 2005 from the sociology literature). Since Granovetter's seminal paper on the embeddedness of economic action in social structure, the social sciences literature has theoretically and empirically advanced our understanding about how social relations affect economic behavior and outcomes. Furthermore, Jackson et al. (2017) emphasize that this interaction is not unidirectional—economic action is affected by and also affects social relations and networks, and thus endogeneity concerns should be addressed when analyzing the role of social networks in economic behavior and outcomes.

One topic that has received considerable attention in the development literature[39] is the role of social networks in migration decisions and outcomes, for both national (typically urban-rural) and international migration. Other topics that have also received attention include job search, dissemination of technology and innovation, pricing when information asymmetries exist, financial arrangements, and risk sharing, among others (Jackson et al. 2017, Granovetter 2005). These studies confirm Granovetter's theory of the embeddedness of economic action in social

[38] Household outcomes (working hours and income) are a result of household decisions and market equilibria.

[39] Woolcock and Narayan (2000: 229) mention nine primary fields of research since the seminal research by Coleman on education and Putnam on civic participation and institutional performance in the early nineties: "families and youth behavior; schooling and education; community life (virtual and civic); work and organizations; democracy and governance; collective action; public health and environment; crime and violence; and economic development." The latter one is the most relevant for this study.

relations and structure, and some of them point to different causal mechanisms behind the effect of social relations on economic behavior.

Of particular interest for this study is the theoretical framework for evaluating the importance of weak ties between individuals, developed by Granovetter and further advanced by others. Weak ties are defined as interpersonal relationships that demand low amounts of time, emotional intensity, mutual confiding, and reciprocal services (Granovetter 1985: 1361). According to Granovetter, "more novel information flows to individuals through weak ties than through strong ties" (2005: 34). Although individuals connected by strong ties have more incentives to intentionally help and cooperate with each other, they usually contribute redundant information to the network because of the tendency to associate with those who share similar interests and characteristics (the so-called homophily pattern that has been confirmed by several studies) and thus tend to access similar information (Jackson et al. 2017: 8-10). Therefore, following Granovetter and others, weak rather than strong ties play a major role in contributing access to other networks and thus new information and opportunities (Granovetter 2005).

Woolcock and Narayan (2000) discuss and classify some of the social capital literature focused on economic development. Building on Granovetter's work, they acknowledge that an important part of the literature classifies social capital as bonding and bridging. Denser networks, typically composed of strong ties within homogeneous groups, are associated with bonding social capital, whereas bridging capital is associated with larger, less dense networks that typically connect heterogeneous groups through weak ties. Woolcock and Narayan (2000: 232) quote Granovetter (1995), arguing that "economic development takes place through a mechanism that allows individuals to draw initially on the benefits of close community membership but that also enables them to acquire the skills and resources to participate in networks that transcend their community, thereby progressively joining the economic mainstream."[40]

In the same line of thought, Sobel (2002) emphasizes that assessing which type of network determines an economic outcome or behavior depends on the particular outcome or behavior under

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[40] Consistent with this line of thought, Giuletti, Wahba, and Zenou (2014) argue that the recurrent finding on the importance of weak ties in the literature on migration has been influenced by the lack of information about the structure of the migrants' networks. They argue that most of the studies on the role of networks in migrants' labor outcomes use a rough proxy for social networks: the share of migrants in the destination country that come from the same community. The authors aim to disentangle the effect of weak and strong ties on migration outcomes in the case of rural-to-urban migration flows in China. They find that both strong and weak ties are important for rural-to-urban migration decisions, acting as complements in their effects on migration. They also find that the weak ties have a larger effect.

analysis. Sobel (2002: 151) argues, quoting Chwe (1999), that "widely scattered weak links are better for obtaining information, while strong and dense links are better for collective action." This caveat is important for this study given the focus on the role of spatially distant yet strong ties in labor income diversification decisions. In particular, we focus on the role of spatially distant, strong ties, involving the household head or spouse's siblings or parents who live in a different province. Even though these ties are expected to be weaker than they would be if they lived in the same town or district, the fact that they are direct family makes them undoubtedly strong ties. Following Granovetter's definition, quoted above, we expect these relationships to entail a high level of emotional intensity, mutual confiding, and, when required, reciprocal services. However, these strong ties are likely to show unusual patterns in the information conveyed within households' closest networks because they have access to information and networks in a distant place of residence. Thus, we argue that these strong ties may behave as weak ties in terms of providing new information and potentially opening up new economic opportunities to the household. If this is true, these distant strong ties may play the role usually attributed to weak ties in Granovetter's theory. Furthermore, these strong ties may facilitate non-farm opportunities to rural households facing increasing climate risk, whenever local shocks or increasing variability is not shared by their family distant location. Also, family living in distant areas may become business partners to rural households, given the mutual trust that usually characterizes family ties. For example, a close relative living close to a dynamic regional market, physically distant from the rural household's town, may have a positive effect on the household livelihood by facilitating the sale of products in the new market, or by merely reducing the accommodation and commercialization costs involved in accessing distant, more profitable markets. In section 4 we test whether this effect is positive or null.[41]

3.3 Data

3.3.1 Household data

Data on household income, working hours, demographics, assets and spatially distant family networks (used to build indicators of spatially distant, strong ties and weak ties) was obtained from

[41] Negative effects could occur as well. For instance, the rural household under analysis could help the distant household by sending remittances that would otherwise be allocated to non-agricultural ventures, reducing the share of non-agricultural labor income that would be expected if the household did not have such ties.

the Provincial Survey of Rural Households (EPHR), conducted in 2014 by the INEI [42]. This survey collected information on 120,012 rural households, and its sample is probabilistic, stratified, and clustered. As previously mentioned, this is the first survey in Peru representative of the rural areas of each province (province is the second-smallest political-administrative unit in Peru, following the smallest one of districts).[43] The analysis in the following section adjusts estimates and standard errors according to the sampling design.

3.3.2 Climate data

Two types of local climate-related data were used in this study:

(i) Local climate parameters of the trimester November-January: 30-year average estimates of mean temperature, intra-seasonal temperature variability (proxied by temperature range: the difference between maximum and minimum temperatures), and mean precipitation.

The climate parameters were estimated by Ponce, Arnillas and Escobal (2015) based on daily information gathered by the National Service of Meteorology and Hydrology (SENAMHI) from over 250 weather stations located across the Andean region.[44] The authors followed closely the methodology used by Lavado, Ávalos, and Buytaert (2015) for the Peruvian chapter of the Evaluation of the Economics of Climate Change project commissioned by the Inter-American Development Bank and the Economic Commission for Latin America and the Caribbean. Aggregated at the district level, the 1982-2012 climate parameters used in this study include areas below 4800 meters above sea level (m.a.s.l.) only, since no agricultural activity is likely to be biologically viable above that level.

(ii) Local occurrence of unexpected extreme climatic events that affected crops or pastures during the previous year: measured by the proportion of farmers who reported having their crops or pastures affected by a climate shock in the district during the previous year. This data was obtained from the EPHR household survey.

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[42] http://webinei.inei.gob.pe/anda_inei/index.php/catalog/287/datafile/F5/V204

[43] The 2006 ENCO was representative each province as a whole, but not of the rural sections of the provinces.

[44] Ponce, Arnillas and Escobal (2015) estimate and discuss climate changes experienced by rural households in the Andean region between 1994 and 2012 (the years when agricultural censuses were performed). To do so, they estimate climate conditions for the 30-year period before each census year: 1964-1994 and 1982-2012. In the present study we use the second estimate only, in order to capture climate conditions relevant to households in our sample.

3.3.3 Data on access to public services and other local socio-economic features

Several indicators were used to characterize local socio-economic features:

- Local access to public services such as safe water or electricity was measured with 2007 Population Census data.

- Land inequality estimates were produced by Ponce, Arnillas and Escobal (2015) with 2012 Agricultural Census data. The authors estimate the Gini coefficient of an equivalent land area, using quality-adjustment ratios proposed by Caballero and Chavez (1980).

- Median hourly earnings in the farm and non-farm sectors were used as proxies for labor productivity as suggested by Hicks et al. (2017). Estimates used EPHR data (representative at provincial level).

- Based on 2012 Agricultural Census data, the percentage of households that allocate most of the yield of at least one plot to the market was used as an indicator of local farm-products market dynamism.

- To account for differences in the degree of violence experienced in each province during the internal conflict, and thus control for differences in its potential consequences on current economic and social dynamics, we use the classification of provinces by high and low violence levels as proposed by Ponce (2010), based on information gathered by the Truth and Reconciliation Commission (CVR 2003).

Household characteristics (demographic, socio-economic, climate and other local environmental conditions) are summarized in Table 3.1.

Table 3.1. Characteristics of rural households in the Andean region.

Average household characteristics and environmental conditions	North	Central	South	All domains
<u>Family income and working hours</u>				
Share of non-farm working hours	23.5	25.6	27.5	25.8
Share of non-farm labor income	26.5	28.5	31.8	29.2
Non-farm working hours	16.9	18.8	20.2	18.8
Farm working hours	39.3	40.6	38.8	39.6
Non-farm labor income [i]	438.0	541.7	627.0	546.0
Farm labor income [i]	446.2	579.0	480.4	510.6
<u>Family socio-demographic characteristics</u>				
Single-headed households (%)	25.6	29.4	30.2	28.7

Average household characteristics and environmental conditions	North	Central	South	All domains
The mother tongue reported by household head and spouse is an indigenous language	2.1	69.5	92.6	60.8
Age of the household head	49.1	50.1	51.5	50.3
Dependency ratio (hh members [<14y,64y] / [14-64])	0.8	0.8	0.7	0.8
Number of household members	3.9	3.7	3.4	3.7
Family network (local and distant)				
Strong distant ties - the household has strong family ties in a different province (at least one sibling or parent of the household head or spouse)	29.4	30.7	23.8	27.9
Local network - the household participates in an organization that can affect economic outcomes (political, governmental planning, productive or commercialization associations) [ii]	15.7	11.1	11.0	12.2
Other assets and forms of capital				
Years of formal education of the most educated hh member	7.2	8.1	7.9	7.8
The household has a second dwelling that it visits frequently	6.4	9.2	10.8	9.1
Access to financial services	29.4	25.7	10.0	21.0
Land size (Owns)	97.8	53.8	59.9	67.0
Local climate conditions (long term and short term)				
Unexpected climate events in the district (% of farmers in the district who had crops or pastures affected by an unexpected climate event during the previous year)	21.1	47.8	73.9	50.4
30-year average temperature (Nov/Dec/Jan)	14.3	11.7	10.3	11.8
30-year temperature range (Nov/Dec/Jan)	11.4	12.5	13.4	12.5
30-year average precipitation (Nov/Dec/Jan)	89.8	93.1	99.8	94.7
Percentage of farmers with irrigation systems (gravity or technified) in the district	28.3	46.0	36.7	38.3

Average household characteristics and environmental conditions	North	Central	South	All domains
Local socio-economic and structural conditions				
Land Gini coefficient (equivalent hectares)	0.7	0.8	0.8	0.8
Product market - Proportion of farmers that allocate most yield from at least one plot to markets	35.4	42.7	25.5	34.7
Non-agricultural sector – median hourly income in the province of residence	24.2	27.6	29.4	27.4
Agricultural sector – median hourly income in the province of residence	6.3	9.0	7.5	7.8
% of households with access to safe water	41.9	44.9	44.7	44.1
The province experienced high violence during the internal conflict (1980's, 1990's) [iii]	20.1	77.3	88.2	66.8
Households	12062	29349	21864	63275

[i] Real income was spatially deflated using the poverty line (ENAHO 2014).
[ii] This excludes other associations such as those focused on cultural and sports activities, health, school or collective food and meals programs.
[iii] Classification by Ponce (2010: 81-82) based on information gathered by the Truth and Reconciliation Commission (2003) for the period 1980-2000.
Source: Own calculations based on data from the 2014 EPHR, 2012 Census of Agriculture , identification of provinces that experienced high violence during the internal war by Ponce (2010), and climate estimates by Ponce, Arnillas and Escobal (2015). Sample weights were used to calculate averages.

3.4 Methods

As previously mentioned, this study focuses on the relative importance of non-farm activities in Andean household livelihoods. Two economic outcomes were analyzed in detail: (i) non-farm income share (proportion of labor income derived from non-farm activities), and (ii) non-farm work share (proportion of family working hours devoted to non-farm activities). To complement and confirm some channels through which climate variability and distant, strong ties affect these two outcomes, we also explored their effect on: (iii) non-farm income level, (iv) number of family working hours allocated to non-farm activities, (v) farm income level, (vi) farm working hours and (vii) family labor income (net).

3.4.1 Intra-seasonal climate variability (explanatory variable)

While household expectations on climate and prices are key to household's initial decisions on resource allocation between farm and non-farm activities, actual weather realizations during the growing season affect final market prices and quantities. Therefore, both expectations and actual climate conditions affect the proportion of household income derived from farm and non-farm activities. Similarly, family work devoted to each activity depend on expectations and actual climate conditions because households can partially adjust initial allocations of work and resources during the growing season as needed (for example, household members could find a non-farm short term employment to compensate for crop loss due to a climate shock occurred during the growing season).[45]

Climate parameters (usually calculated as 30-year averages) such as the mean and variability of temperature, precipitation and wind are used in the climate literature to characterize the probability distribution of weather conditions in a particular period or location (IPCC 2014b). As Ponce (2020: 6-7, based on IPCC, 2014; Carleton and Hsiang and Folland, 2016; Karl and Sallinger 2002) explains in detail, extreme weather may be the result of a change in mean temperature, in temperature variability, or in both. Whereas an increase in mean temperature with no change in variability increases the probability of extremely hot weather, an increase in temperature variability with no change in means may also increase the probability of extreme weather (both hot and cold). Therefore, identifying the role of an increase in temperature variability requires taking into consideration both parameters, mean and variability.[46] As previously mentioned, we hypothesize that the effect of temperature variability on non-farm income share is stronger in colder areas, because farm activities are more vulnerable to cold extreme weather during the growing season[47] (Ponce 2020). This effect is captured by an interaction term (temperature mean • variability) in the econometric specification.

As previously discussed in Section 2, in addition to climate parameters characterizing local climate during the growing season, complementary controls are included in the specification:

(i) household characteristics that account for farmers differences in perceptions, access and interpretation of information on climate conditions and trends, such as the household head's age

[45] See Appendix 1 for an outline of a three-period model of household income diversification decisions.
[46] There is no available information at local levels either on wind or on variability of precipitation. Only mean precipitation is included as control in the econometric analysis.
[47] Given the temperature range in the region, extreme cold events may cause crop loss, whereas extreme hot events are more likely to increase the incidence of pest and disease. Although the latter may be critical and lead to crop loss, there are farm practices (technologies and inputs) that may help producers substantially reduce such risk.

and cultural background (proxied by whether the first language of the household head and/or his spouse was an indigenous language) and highest education achieved by one of the household members;

(ii) local access to irrigation (which may reduce the effect of changes in temperature or precipitation on farm productivity[48]); and

(iii) the proportion of local farmers who reported that a climate shock significantly affected their crops and pastures (the higher the proportion, the higher the probability that the focal farmer was affected as well and the higher the impact on local market prices).

3.4.2 Spatially distant, strong ties (explanatory variable)

Spatially distant, strong ties are proxied by household's direct family living permanently in distant areas (siblings or parents of the household head or spouse who live in a different province). This study argues that distant, strong ties may become a form of social capital as long as they can provide new information for economic activities that would otherwise be unknown to the household (new products, new markets, new technologies), and can also reduce the transaction costs involved in accessing new markets.[49] It is worth to mention, nevertheless, that distant ties may have a zero or even a negative effect in some cases. Distant, strong ties may have no impact on household economic decisions if the household has a second residence close to more dynamic markets, or may even be associated with lower economic outcomes when the household's distant family is in critical need, or when the absence of strong ties in local areas is related to a systematic emigration of community members that weakens traditional community strategies for coping with risk (Valdivia et al. 2010). It could also be argued that such ties may become redundant when other families in the community have distant, strong ties; in other words, it may be important to have such an asset at the community level, but it eventually becomes redundant at the individual level. Even further, as previous literature discusses, local networks may play a bigger role in extra-local market access. Given these potential complexities, besides estimating the direct effect on economic outcomes and the role that these networks have on the response to climate variability (interaction term), the econometric specification controls for: (i) complementary extra-local

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[48] Due to endogeneity issues and the fact that not all households work their own farms, we cannot control for irrigation at individual level.

[49] Although this effect could be important for both farm and non-farm activities, we expect that when local weather shocks or more variable climate conditions take place this effect on farm activities will be stronger. Unfortunately, testing whether this is the case (and linking both hypothesis of the study) would require additional data not yet available.

networks: the proportion of local households that have distant, strong ties, (ii) whether the household owns a second residence, (iii) local networks: whether a household member participates in an organization that can affect economic outcomes, such as political, governmental planning, productive or commercialization associations, and (iv) other household characteristics associated with household's ability to convert social capital into actual economic opportunities; such characteristics include household' highest level of education achieved by one of its members, access to public services, dependence ratio, bi-parental status, among others.

3.4.3 The econometric specification

The key challenge to the estimation lies on the non-Normal distribution of most outcome variables, not only at the regional level but within domains as well (Figure 3.4). To overcome this issue, we use a generalized linear model (GLM) framework (Hardin and Hilbe, 2018)[50]. Defining *y* as the outcome variable (non-farm income share, for example) and *x* as the vector of covariates (such as climate variability or distant, strong ties), we estimate:

$$g\{E(y)\} = \boldsymbol{x}\beta \text{ , } y \sim F \qquad (1)$$

where *g{.}* is the link function and *F* is the distributional family [51]. For positively skewed, non-negative outcomes with different dispersion patterns, the Gamma distribution as well as the Poisson and Gaussian families where explored. Logit link functions were preferred for ratio outcomes (hours and income shares), whereas log and identity link functions were suitable for outcomes in levels. We allowed for different specification (and heterogeneous parameters) across outcomes and geographical domains [52]. Given the nature of the survey data, we adjusted standard errors by stratified and clustered sample design.

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[50] GLM models allow to relax the normality (and constant variance) assumptions required for inference in linear models. Linear regression is a particular case of GLM (Normal family with identity link function).

[51] This reduced form model departs from the structural form in that it excludes endogenous variables, such as those determined in equilibrium when considering supply and demand equations. Appendix 1 outlines the 3-period model. While in the first period the initial allocation of work and resources between farm and non-farm activities is made, in the second period a climate shock may occur and households may reallocate (partially) family work to compensate for potential crop loss, and in the third period market prices and quantities are determined and thus household final outcomes (income and work) are known.

[52] A specification test based on Pregibon (1979) was performed on alternative versions using Stata's *linktest*. Three outcome variables did not pass the test and therefore are not discussed in the following section: for the South, Non-farm income level and Non-farm hours; and for the Central Andes, Farm income level (Table 3.5 and Table 3.6 of Appendix 3).

x represents the vector of covariates that may affect household outcomes. Household characteristics that may facilitate or limit its ability to pursue each activity (farm and non-farm) included: (a) its resources, including family labor available (proxied by number of household members), land assets, access to financial institutions, work experience (proxied by household head's age), the highest level of formal education in the household, whether the household owns a second residence that its members visit frequently, and household networks that may become social capital in local and distant areas (local networks; distant, strong ties; distant weak ties), and (b) the constraints faced by the household such as whether it is mono-parental, and the ratio between dependent members (young children, elders, or sick members) and income earners within the household (this ratio was proxied by the so-called dependence ratio).

As mentioned previously in this section, climate conditions may affect both household decisions and final market prices and transactions. The estimated models include three 30-year climate parameters at district level: temperature mean, temperature variability and mean precipitation. To isolate the effect of an increase in temperature variability from the effect of changes in temperature mean[53] we introduced the interaction between both parameters (section 4 discusses the effect of temperature variability across the mean temperature gradient). Additionally, we interact these two climate parameters with the dummy of household distant, strong ties. This interaction was used to identify whether household's distant, strong ties facilitate non-farm income opportunities as a response to increasing climate variability.

Household economic outcomes are also affected by local or regional factors, such as how dynamic labor, land, input, and product markets are. The expected returns of each activity are likely to affect household diversification strategies. Following Hicks et al. (2017), we use the provincial average hourly income for each activity (agricultural and non-agricultural) as a proxy for labor productivity. More structural characteristics may affect the household's decision as well, such as the degree of inequality in land distribution. This indicator may reflect other institutional differences in access to land and other natural resources as well. While land is fragmented rather than concentrated and under the control of peasants' communities in some areas of the Andean region, some other regions have more fluid land markets (for rent and sale), allowing potential

[53] As it was previously mentioned, climate risk in the Andean region usually materializes as a higher incidence of hail and freezing events, and a higher incidence of pests and disease due to warmer temperatures. It is key to the identification strategy to isolate the effect of an increase of temperature variability with unchanged means (which would entail an increase in the probability of extremely high and low temperatures) from the effect of an increase in temperature means with unchanged variability (which would entail an increase in the probability of extremely high temperatures).

concentration and price fluctuations. Complementarily, we added a dummy for provinces that experienced high rates of violence during the internal conflict, to capture long-term consequences that may have eventually affected the structure of social networks (trust, local bonding social capital, or bridging capital, among other features).

3.5 Results and discussion

As previously mentioned, the Andes is a mountainous region with very diverse environmental conditions, ranging from 500 m.a.s.l. to 6768 m.a.s.l. During the crop growing season mean temperature parameters range between 9 and 20˚C, 5 and 18˚C and 4 and 17˚C across the Northern, Central and Southern domains, respectively[54] (Ponce 2020: 8). In spite of these moderate mean climate conditions, the difference between (30-year averages of) minimum and maximum temperatures oscillate between 9 and 13˚C, 9 and 15˚C and 10 and 17˚C across Northern, Central and Southern domains, respectively (Table 3.1, Figure 3.6). While mean temperatures have increased throughout the Andean region in the last decades, temperature variability has shown heterogeneous trends, with higher prevalence of increasing variability in the Central and Southern Andes (Ponce, 2020: 8-9). Besides climate differences, topographic, cultural and socio-economic differences are substantial across the region and, as discussed here, households' response to increases in climate variability is heterogenous across domains.

3.5.1 Do Andean households respond to increasing climate variability by diversifying more into non-farm activities?

The short answer is yes in the Northern and Central Andes, but not in the South. The estimates for the Central and Northern Andes confirm the hypothesis that an increase in intra-seasonal climate variability leads to an increase in the relative importance of non-farm income and working hours (Table 3.2 – average marginal effect). When looking across the mean temperature gradient (Figure 3.1), we find that this effect is stronger in cooler areas (26% and 73% of Northern and Central households live in areas with mean temperatures below 13˚C, respectively). Beyond the relative importance of non-farm activities (compositional effect), we confirmed that households respond to an increase in climate variability by increasing (decreasing) non-farm (farm) working hours and non-farm (farm) income levels (Figure 3.7).

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[54] These ranges are determined by 30-averages of minimum temperatures and maximum temperatures in each domain. Only areas below 4800 m.a.s.l. are considered.

Table 3.2. Average marginal effects on (i) non-farm working hours share and (ii) non-farm labor income.

Covariates	Share of non-farm labor income Gamma, logit North	Share of non-farm labor income Gamma, log Central	Share of non-farm labor income Gamma, logit South	Share of working hours allocated to non-farm activities Gamma, logit North	Share of working hours allocated to non-farm activities Gamma, log Central	Share of working hours allocated to non-farm activities Gamma, logit South
Single-headed household dummy	0.050***	0.048***	0.028**	0.078***	0.053***	0.032**
	(0.015)	(0.011)	(0.014)	(0.015)	(0.011)	(0.013)
The mother tongue reported by household head and spouse is an indigenous language	0.117	-0.044***	-0.053**	0.086	-0.042***	-0.064***
	(0.082)	(0.012)	(0.022)	(0.069)	(0.011)	(0.021)
Age of the household head	-0.002***	-0.003***	-0.005***	-0.002***	-0.003***	-0.005***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Dependency ratio (hh members [<14y,64y] / [14-64])	-0.020**	-0.027***	-0.041***	-0.022***	-0.022***	-0.035***
	(0.008)	(0.006)	(0.007)	(0.007)	(0.006)	(0.007)
Years of formal education of the most educated hh member	0.029***	0.037***	0.027***	0.028***	0.034***	0.025***
	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)
Number of household members	-0.008***	0.000	0.016***	-0.005*	-0.001	0.013***
	(0.003)	(0.002)	(0.003)	(0.003)	(0.002)	(0.003)
Strong distant ties - the household has strong family ties in a different province (at least one sibling or parent of the household head or spouse)	0.015	0.021**	0.022*	0.009	0.019**	0.019*
	(0.012)	(0.009)	(0.013)	(0.011)	(0.008)	(0.011)
Weak ties (% of households in the district with strong distant ties)	0.072	-0.007	0.144**	0.087	-0.004	0.171***
	(0.064)	(0.038)	(0.063)	(0.059)	(0.036)	(0.058)
Local network - the household participates in an organization that can affect economic outcomes (political, governmental planning, productive or commercialization associations) ii	-0.065***	-0.021	0.019	-0.061***	-0.027**	0.003
	(0.017)	(0.014)	(0.019)	(0.015)	(0.012)	(0.016)

Covariates	Share of non-farm labor income Gamma, logit North	Share of non-farm labor income Gamma, log Central	Share of non-farm labor income Gamma, logit South	Share of working hours allocated to non-farm activities Gamma, logit North	Share of working hours allocated to non-farm activities Gamma, log Central	Share of working hours allocated to non-farm activities Gamma, logit South
The household has a second dwelling that it visits frequently	0.047**	0.038***	0.053***	0.056***	0.043***	0.044***
	(0.021)	(0.013)	(0.016)	(0.020)	(0.012)	(0.014)
Access to financial services	-0.003	0.038***	0.094***	-0.002	0.033***	0.078***
	(0.013)	(0.011)	(0.018)	(0.012)	(0.010)	(0.017)
Land size (Owns)	-0.000**	-0.000	-0.000*	-0.000	-0.000	-0.000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Unexpected climate events in the district (% of farmers in the district who had crops or pastures affected by an unexpected climate event during the previous year)	-0.000	-0.039	0.052	0.030	-0.054**	0.044
	(0.048)	(0.027)	(0.045)	(0.042)	(0.025)	(0.043)
30-year average temperature (Nov/Dec/Jan)	-0.005	-0.004	-0.010*	-0.007	-0.001	-0.005
	(0.007)	(0.004)	(0.006)	(0.006)	(0.004)	(0.005)
30-year temperature range (Nov/Dec/Jan)	0.050**	0.024***	-0.010	0.047**	0.021***	-0.006
	(0.025)	(0.008)	(0.009)	(0.023)	(0.008)	(0.008)
30-year average precipitation (Nov/Dec/Jan)	0.001***	0.000	-0.000	0.001**	0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Percentage of farmers with irrigation systems (gravity or technified) in the district	-0.055	-0.044*	-0.012	-0.041	-0.048**	-0.024
	(0.050)	(0.025)	(0.034)	(0.046)	(0.024)	(0.031)
Land Gini coefficient (equivalent hectares)	0.559***	0.290***	0.022	0.570***	0.295***	0.029
	(0.141)	(0.065)	(0.089)	(0.131)	(0.064)	(0.083)
Product market - Proportion of farmers that allocate most yield from at least one plot to markets	-0.186***	-0.052*	0.183***	-0.199***	-0.083***	0.172***
	(0.041)	(0.030)	(0.046)	(0.038)	(0.029)	(0.043)
Non-agricultural sector – median hourly income in the province of residence	-0.010***	-0.001	-0.002	-0.011***	-0.004***	-0.003
	(0.003)	(0.002)	(0.003)	(0.002)	(0.002)	(0.002)
Agricultural sector – median hourly income in the province of residence	-0.002	-0.001	-0.009***	-0.001	0.001	-0.007***

Covariates	Share of non-farm labor income Gamma, logit North	Share of non-farm labor income Gamma, log Central	Share of non-farm labor income Gamma, logit South	Share of working hours allocated to non-farm activities Gamma, logit North	Share of working hours allocated to non-farm activities Gamma, log Central	Share of working hours allocated to non-farm activities Gamma, logit South
	(0.004)	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
% of households with access to safe water	0.071	0.147***	0.153***	0.051	0.154***	0.126***
	(0.056)	(0.030)	(0.049)	(0.052)	(0.028)	(0.046)
The province experienced high violence during the internal conflict (1980's, 1990's) iii	-0.047**	-0.000	-0.028	-0.057***	0.000	-0.052*
	(0.020)	(0.017)	(0.033)	(0.017)	(0.016)	(0.030)
Observations	12,060	29,345	21,860	12,060	29,345	21,860

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1

[i] Real income was spatially deflated using the poverty line (ENAHO 2014).

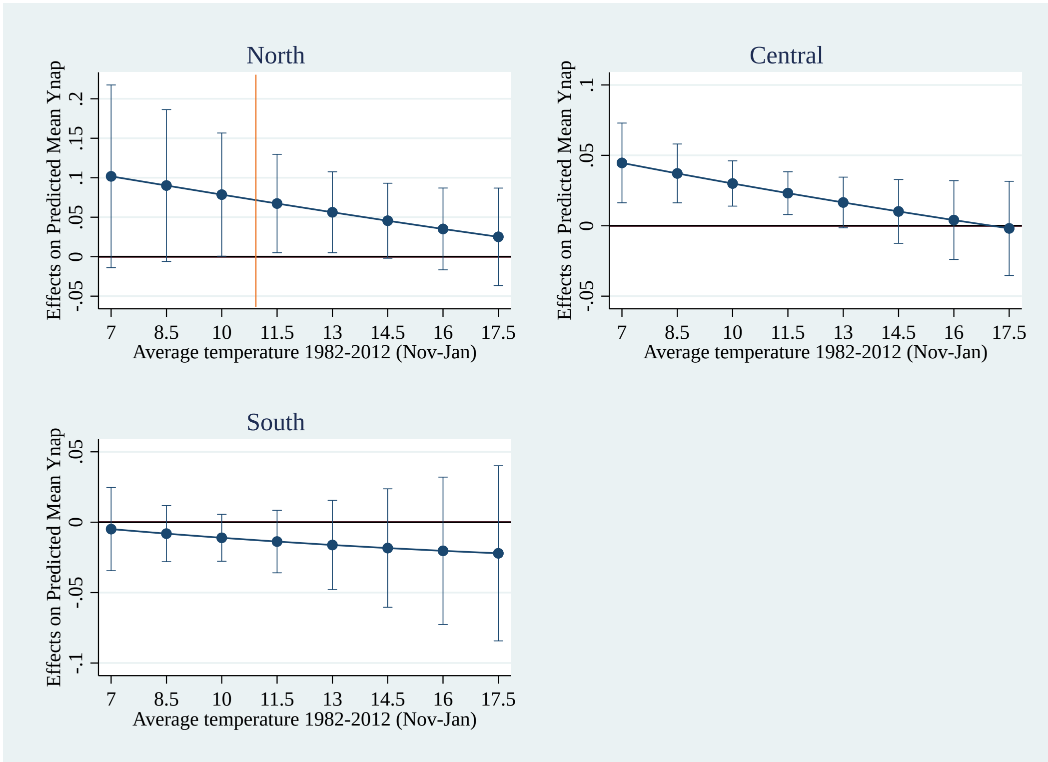
[ii] This excludes other associations such as those focused on cultural and sports activities, health, school or collective food and meals programs.

[iii] Classification by Ponce (2010: 81-82) based on information gathered by the Truth and Reconciliation Commission (2003) for the period 1980-2000.

Note: The estimates were adjusted by the sample design (stratified and clustered random sample).

Source: own estimates based on data from the 2014 EPHR, 2012 Census of Agriculture, identification of provinces that experienced high violence during the internal war by Ponce (2010), and climate estimates by Ponce, Arnillas and Escobal (2015).

Share of Non-Farm Income



Share of Non-Farm Working Hours

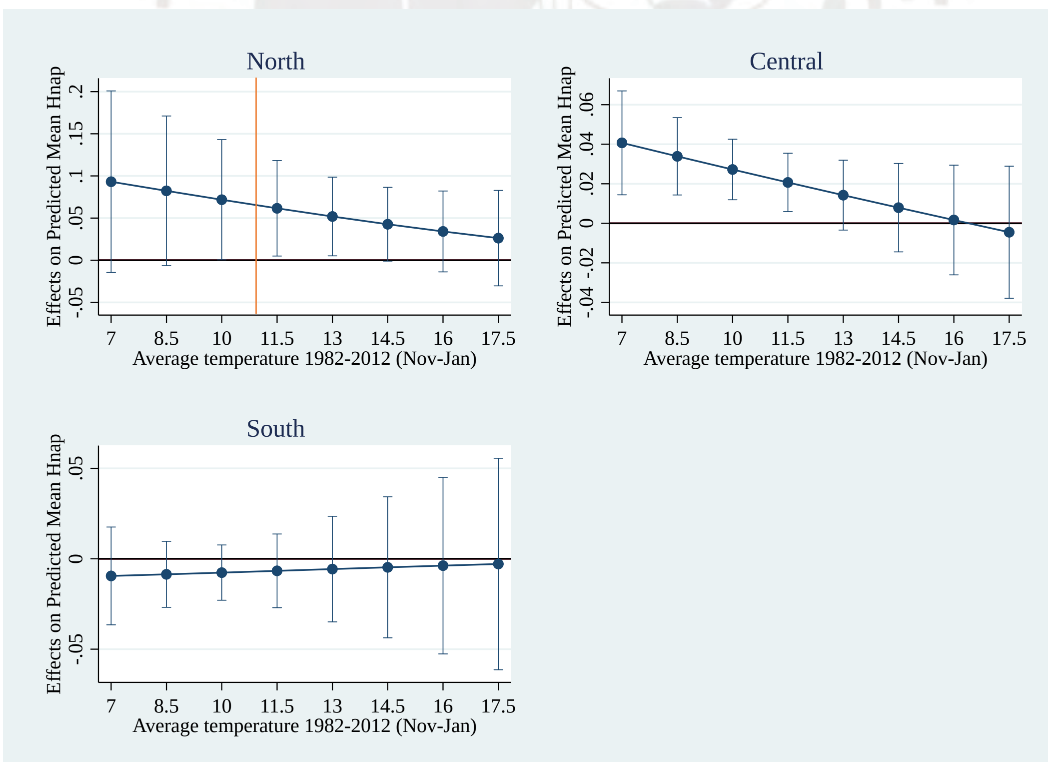


Figure 3.1. Effect of intra-seasonal climate variability on income diversification strategies (share of non-farm income and share of non-farm working hours) in the Andean region, by mean temperature.

The figure shows the average marginal effect of temperature range on non-farm income share, setting mean temperatures at specific values. Parameters were independently estimated for each domain using generalized linear models with distributional families and link functions specified in Table 3.2. Due to low prevalence of mean temperatures below 11˚C in the northern domain (Figure 3.7), only results above that threshold should be considered. The figures show a positive effect below 13˚C in the North and Central domains, whereas no statistically significant effect is found in the South.

In the Southern domain, on the other hand, results are quite different. While the effects of intra-seasonal climate variability on the shares of non-farm income and non-farm working hours are statistically insignificant, we find that households respond to higher climate variability by increasing farm hours with no extra economic return (Table 3.5 and Table 3.6). This is consistent with a previous study in the area, where Ponce (2020) found that Southern farmers respond to higher climate variability by increasing crop portfolio concentration in favor of crops that better tolerate diverse environmental conditions, instead of adapting intercropping practices (which would require information and technical assistance, but with potentially higher and more sustainable returns). Putting together both studies suggests that Southern farmers respond to higher climate variability (higher risk) by working more on their farms but with lower productivity. If this is the case, Southern farmers are the most vulnerable to increases in climate variability in terms of non-monetary wellbeing; whereas their peers in the Northern and Central domains shift towards non-farm income sources[55], Southern rural households seem to seek refuge in lower-return farm activities.

3.5.2 Are distant, strong ties real assets for household non-farm income generating activities?

According to our estimates, distant strong ties do have a positive role in facilitating Andean households non-farm income opportunities. This result is clear for Central and Southern areas (Table 3.2). Still, in the Northern areas -where no significant effect is found in non-farm shares- we find that households with distant strong ties allocate more hours to non-farm activities (Table 3.5) and obtain higher labor income (Table 3.6) than those who do not have such ties.

As mentioned in Section 3.2, previous literature discusses in detail the role that different types of networks can have in household income generating strategies. Complementary to (or even substitute of) distant strong ties, a household can access new information and business

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Table 3.7. of the Appendix 3 shows results of a preliminary estimation on labor income levels (net), where no average marginal effect of climate variability is found in any domain.

opportunities (local or extra-local) through ties that other local households have in distant areas (this is what we call distant, weak ties in the regression tables). This is especially true in tightly knit rural communities. Therefore, we control for distant, weak ties. Table 3.2, Table 3.5 and Table 3.6 show that these weaker ties out of the household territory have no major role in non-farm diversification strategies in Northern and Central areas, but they do in the South. We find that Southern households with distant, weak ties diversify more into non-farm activities (hours and income share) and allocate less hours to farm activities [56].

Lastly, as mentioned before, local networks are the most widely studied type of network in the rural development literature. We included a proxy for local networks that comprises participation in organizations that may influence household access to economic opportunities (productive, commercialization, political or governmental planning organizations). As expected, these organizations have a non-negative effect on farm activities and a non-positive effect on non-farm activities across all domains (Table 3.3). Still, some differences arise across domains. Central and Northern areas, more connected to markets and cities show that households with local networks tend to diversify less into non-farm activities; yet, in the Central Andes households with local networks obtain higher farm income than their peers lacking such networks -ceteris paribus-. The role of local networks on farm outcomes is stronger in the South [57].

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[56] Although distant, strong ties may be correlated with lower access to land in areas with strong peasant communities that maintain control over land and water access, weak ties should not capture such correlation. Still, this is a topic that requires further analysis.

[57] It was not possible to explore the role of such networks on non-farm activities in the South, due to econometric specification issues.

Table 3.3. Summary of statistically significant parameters on climate variability, distant strong ties, distant weak ties and local networks.

Domain	Outcome	Climate variability - RT	Distant, Strong Ties - DST	Distant Weak Ties - WST	Local networks - Local	Outcome	Climate variability - RT	Distant, Strong Ties - DST	Distant Weak Ties - WST	Local networks - Local
North	Non-farm income share	+ **			- ***	Labor income		+ **	+ **	
	Non-farm hours share	+ **			- ***					
	Non-farm income	+ ***			- ***	Farm income	- ***		+ **	+ **
	Non-farm hours	+ ***	+ ***		- ***	Farm hours	- ***		- **	
Central	Non-farm income share	+ ***	+ **			Labor income				
	Non-farm hours share	+ ***	+ **		- **					
	Non-farm income	+ ***		- ***	- ***					
	Non-farm hours	+ ***	+ ***		- ***	Farm hours	- ***		- **	
South	Non-farm income share		+ *	+ **		Labor income			+ **	
	Non-farm hours share		+ *	+ ***						
						Farm income				+ **
						Farm hours	+ ***	- *	- ***	+ ***

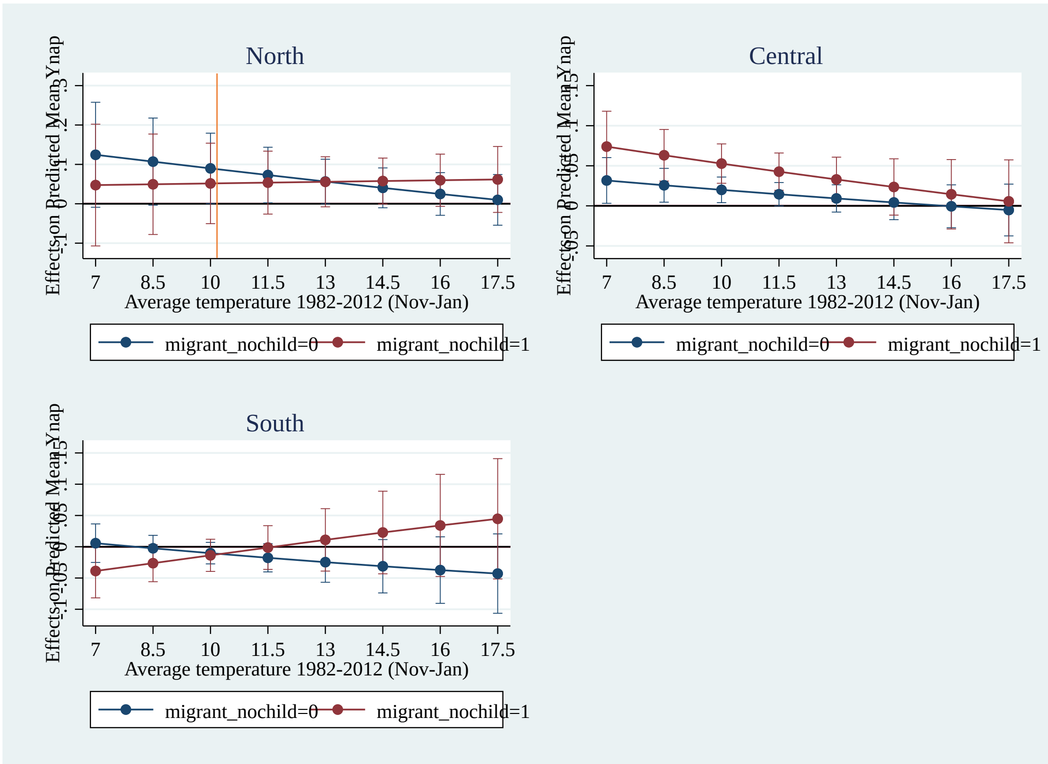
Note. GLM parameters presented in detail in Table 3.2 and Table 3.5. *** p<0.01, ** p<0.05, * p<0.1. In gray: models with specification issues.

3.5.3 Do distant, strong ties facilitate household adaptation to increasing climate variability?

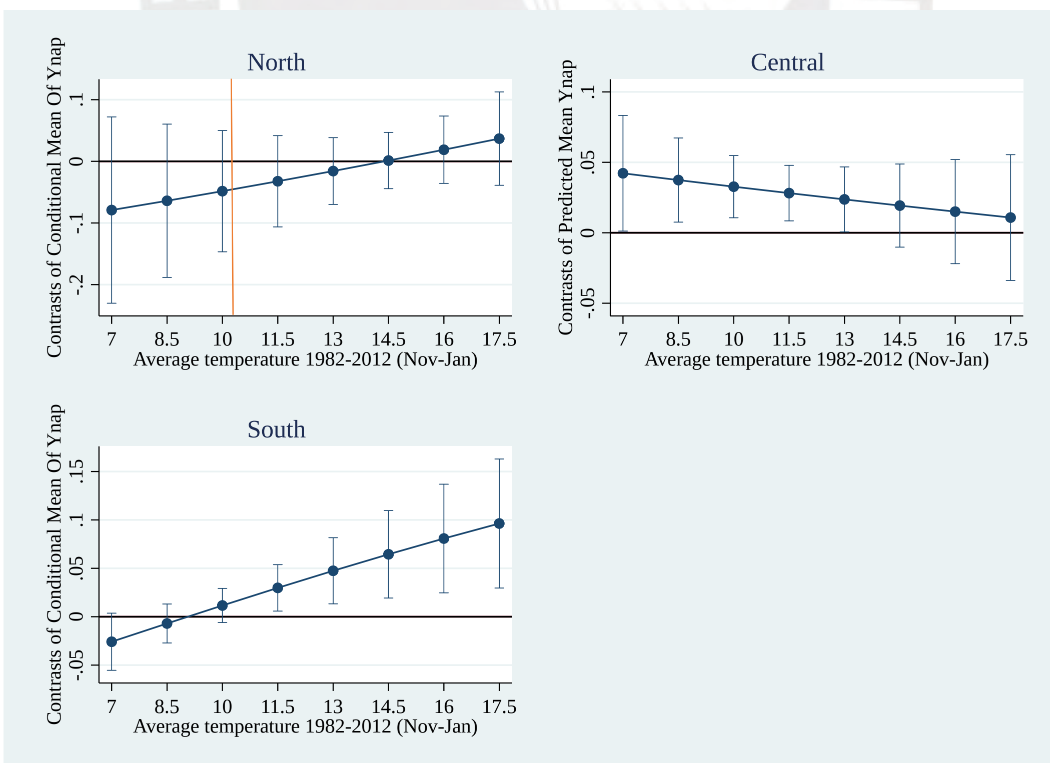
Interestingly, our results suggest that distant, strong ties facilitate household adaptation to increasing climate variability via non-farm activities in the Central and Southern Andes. Figure 3.2 shows the expected household response to an increase in temperature range assuming two scenarios, with and without distant, strong ties. While Northern households show no difference, Central and Southern estimates suggest that distant, strong ties facilitate household response to higher climate variability by increasing its involvement in non-farm activities. This result is found for Central areas with mean temperatures below 13˚C (where 73% households live, Figure 3.9) and for southern areas with mean temperature above 11.5˚C (where 22% households live, Figure 3.9).

Share of Non-Farm Income

(a) Marginal effect of climate variability for households with- and without distant, strong ties

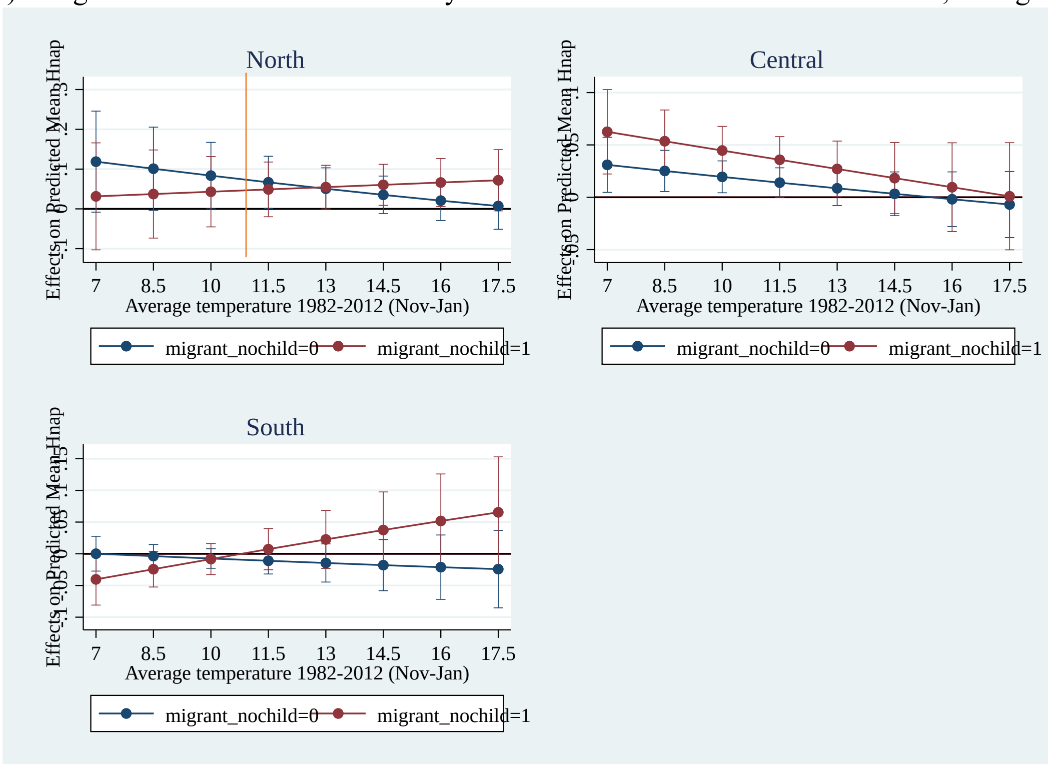


(b) Contrast between households with- and without distant, strong ties



Share of Non-Farm Working Hours

(a) Marginal effect of climate variability for households with- and without distant, strong ties



(b) Contrast between households with- and without distant, strong ties

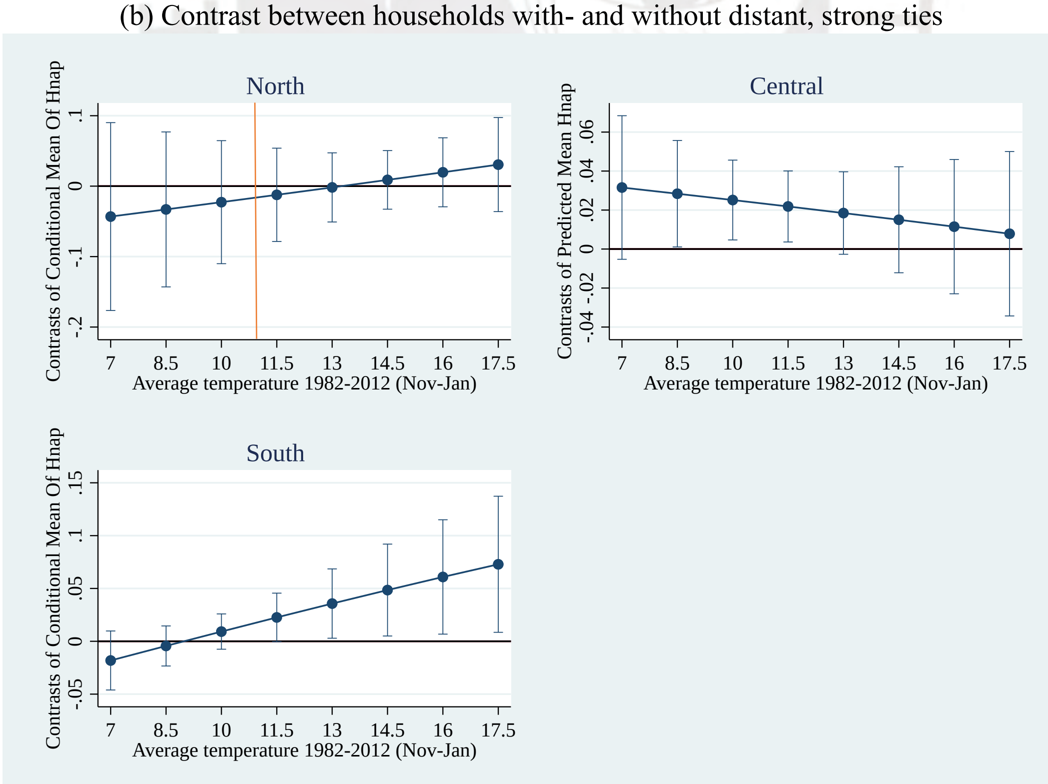


Figure 3.2. The role of distant, strong ties in household adaptation to climate variability. Contrast between the effect intra-seasonal of climate variability on income diversification strategies for households with and without distant, strong ties, by mean temperature.

(a) These figures show the average marginal effects of temperature range on non-farm income share, setting mean temperatures at specific values, for households with distant, strong ties (red line) and without such ties (black line). (b) These figures show the statistical significance of the difference between the responses of the two types of households. In Central and Southern domains households with distant, strong ties show a stronger response to increasing climate variabilities. Parameters were independently estimated for each domain using generalized linear models with distributional families and link functions specified in Table 3.2.

Notably, in the Southern Andes, where climate variability increases the relative importance of farm income sources, we find that households with spatially distant ties have higher non-farm income shares. Although at first this may seem a good sign in terms of access to non-farm income opportunities, we cannot directly corroborate this result because of specification issues with the non-farm hours and income levels models. Nevertheless, results of the farm hours and income level models show that households with distant strong ties respond with lower farm working hours and income levels to higher climate variability whereas show no difference in net labor income when compared to their peers with no distant, strong ties. This suggests that households with strong, distant ties allocate less time and resources to farm activities (thus working less hours and obtaining lower farm income) and increase their non-farm income and working hours. Furthermore, Southern households benefit from their neighbors' spatially distant family ties, showing certain degree of substitution between distant strong and weak ties.

These results suggest that interventions aimed at increasing economic opportunities for rural households could benefit from information and communication technologies and other resources that enhance households' ability to capitalize on their spatially distant networks.

3.5.4 Final comments on other determinants of household diversification into non-farm income sources

As previously mentioned, several controls were included in these estimations. Although these are not the focus of the study, it is interesting to note that most of the estimated parameters show the expected signs. In particular, the findings on the role of demographic characteristics and education are consistent with previous literature about non-farm income (Laszlo 2008, Escobal

2001, Reardon et al. 2001, among others). In most cases, results are similar for both versions of the models of income and working hours (share and level).

Regarding household demographics, it is important to mention that 66% of single-headed households are led by a woman, and 90% of female-headed households are single-headed. In the Andean region, male-headed households tend to have more access to land and other resources (especially in Southern and Central highland communities where traditional institutions control access to land and water), and thus it is not surprising that being a single-headed household is found to be associated with having, ceteris paribus, a higher non-farm income share, lower farm income level and lower net labor income. The age of the household head is also a significant factor in the decision about income diversification strategies, not only because younger household heads are less likely to access land controlled by communities, but also because of the skills required to venture into non-farm activities.

As expected, education plays a key role in income diversification strategies. Given that household members have a key role in the decisions about income-generating strategies in rural areas (as opposed to the traditional idea that households depend mainly on the household head), we control for the maximum level of education achieved by any of the household members. Even if the household head or spouse have limited formal education, their children may provide the skills needed to embark on more profitable activities (either agricultural or non-agricultural). We find that more educated households have higher non-farm income (and hours) shares, as well as higher non-farm income levels and net labor income.

Finally, the number of household members and the dependency ratio capture the role of the demographic structure of the family. While more household members can mean a larger labor force and additional skills to contribute to the family livelihood, having too many children or elder members relative to economically active members can be burdensome for the household limiting its possibilities for engaging in profitable economic activities, especially when these require working outside the farm. The estimation results in Table 3.5, Table 3.6 and Table 3.7. show that, controlling for the dependency ratio, the number of family members does positively affect the income levels that households generate from each activity, as well as the number of hours allocated to either farm or non-farm activities. When looking at the income share and hour shares regressions (Table 3.2), however, we find that these positive relationships holds for Southern households only (not significant in Central areas and negative in the Northern region). Other assets such as land size, access to financial services, and a second dwelling (nearby, in the same district in most cases) show the expected signs. Whereas an increase in land size is associated with higher farm income, access to financial services and owning a second dwelling favors non-farm activities. Interestingly, in the South owning a second dwelling is also associated with higher farm income.

Besides household characteristics and assets, the estimation controls for local conditions, some of them directly related to the household's economic activities, and others indirectly affecting its outcomes through their effects on market and social institutions.

In regard to market dynamics, as Table 3.6 show, an increase in the Northern and Southern[58] province's agricultural labor productivity increases the incentive to work in the agricultural sector, thus increasing both working hours allocated to farm activities (wage and self-employment) and the derived farm income. Non-farm income shares lower in the Northern and Central areas but show no change in the South.

In turn, an increase in the province's non-farm productivity, ceteris paribus, increases household non-farm income and reduces non-farm hours in Central areas but has no effect on income shares and a negative in hours shares. Furthermore, in Northern areas we find a decrease in non-farm hours (with no change in non-farm income, consistent with increases in local productivity) and an increase in farm income and hours, suggesting cross-sector spillover effects. Nevertheless, we call for a cautious interpretation of these parameters, given that the non-farm sector in rural economies is highly heterogeneous.

Finally, as discussed in previous literature, improved access to public services induces an increase in non-farm income levels and share. Based on hours model results, the negative effect on income seems to be induced by the lower number of hours allocated to farm activities.

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[58] As previously mentioned, specification issues prevent us from discussing results for Central areas.

Canadian Economics Association at Antigonish, for their contributions to an early draft. Remaining errors are, of course, my responsibility.

3.6 References

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EPHR 2014 – Provincial Survey of Rural Households.

CENAGRO 1994, 2012 – National Censuses.

3.7 Appendices

3.7.1 Appendix 1. Outline of the Model.

Household decisions about income diversification strategies depend on resources they control as well as on factors they do not control (or know of in advance) but substantially affect their economic outcomes. Factors that households cannot control include climate conditions affecting livestock and crop yields, and market prices of the goods and services households sell or need to buy. Household expectations about these factors are key to the initial allocation of resources to each of economic activity the household pursues. Ultimately, regardless of whether household expectations on climate conditions or prices matched actual values, actual conditions also affect final economic outcomes. Therefore, studying the effect of climate conditions on the non-farm income share requires conceptual consideration of both household (*ex-ante*) expectations and actual (*ex-post*) realizations of climate conditions.

The model that underlies this study is described in this section. Households aim at maximizing their wellbeing, which can be proxied by consumption and leisure. To do that, households decide on the number of working hours and resources to invest in each activity that they choose to pursue. As a result, they produce goods and services, earning an income. In this model, income can be earned by selling goods or services produced at home or by working for an employer; or it can be the financial equivalent of the goods that households produce and consume. For simplicity in this model, the household is the decision unit, so the model does not explicitly account for inequalities within the household, or for differences in power or preferences among household members.

To track the role of intra-seasonal climate variability in the households' economic outcomes of interest, let's assume there are three periods (

Figure 3.3). In the first period, before the crop growing season, households make initial decisions about how much of their resources to invest in each activity (farm or non-farm) based on their expectations on climate conditions during the crop growing season as well as their expectations on post-harvest market prices.

Accordingly, in the first period, households maximize their expected utility W_i:

$$Max_{H_{ij}Z_{ij}C_i} E(W_i) = f(consumption, leisure, ..)$$

subject to several constraints:

Household resource constraints. There are finite resources available to the household, including the number of working hours H_i that family members can supply to generate income (typically age and gender demographics within the household affect how much family labor is available for income-generating activities); household members' experience in sector *j*; land, tools, and equipment available for performing activity *j*; social capital (including household distant, strong ties and local networks, as well as other local households' ties in distant areas); access to credit and financial institutions; among other resources.

A production function for each sector *j*. For on-farm activities, the production function depends on climate conditions, among other factors. Thus, household expectations on the climate conditions that will take place during the crop growing season affect household decisions about the crop portfolio and the amount of resources allocated to farming. If the household expects bad climate conditions for the crop growing season, it will tend to invest more in non-farm activities and less in farm activities. Based on previous studies about household climate expectations, this model assumes that these expectations depend on the household head's age, education, and experience in farm activities, the climate shocks affecting local pastures and crops in the previous year, as well as on parameters of local climate distribution.[59]

Monetary restrictions. Labor income generated from all activities (farm and non-farm) and non-labor income derived from public and private transfers, rents, and extraordinary income must cover total production costs and household consumption.

The second period is the crop growing season. If an unexpected extreme event occurs, crops, pastures, and/or animals will be affected. In the worst-case scenario, households lose production from the entire farm. They reallocate remaining working hours to a non-farm activity or farm wage employment in a distant area where no extreme climate event occurred and thus partially compensate for the on-farm production losses. Households with distant, yet strong ties could have better opportunities to face such local climate risks. Finally, in the third period, harvest and market transactions occur. In this period farm and non-farm production levels as well as prices are known, and households consume or sell their products to the market, obtain income from the other activities they performed in the second period, and buy consumption goods and services. Both

[59] This model is suitable for a regular year, when no major climate events such as a strong El Niño or La Niña occur during the crop growing season. Since these events are sometimes announced by governmental agencies and the media, some farmers are better informed than others about the severe conditions they will face, and thus systematic differences may be found in the parameters between well-informed and uninformed groups. Most importantly, the estimated association between long-term local average climate conditions and households' final economic outcomes would hardly be robust in those irregular years.

income levels and the number of hours worked in each activity may differ from those initially allocated by the household.

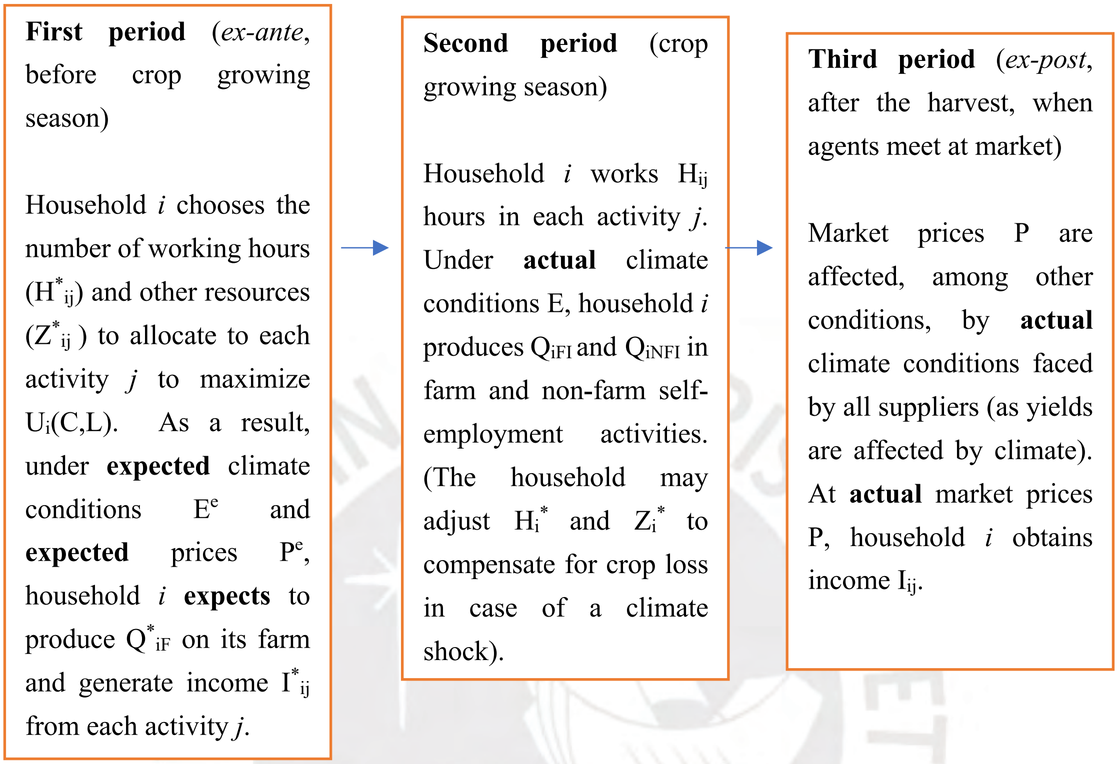
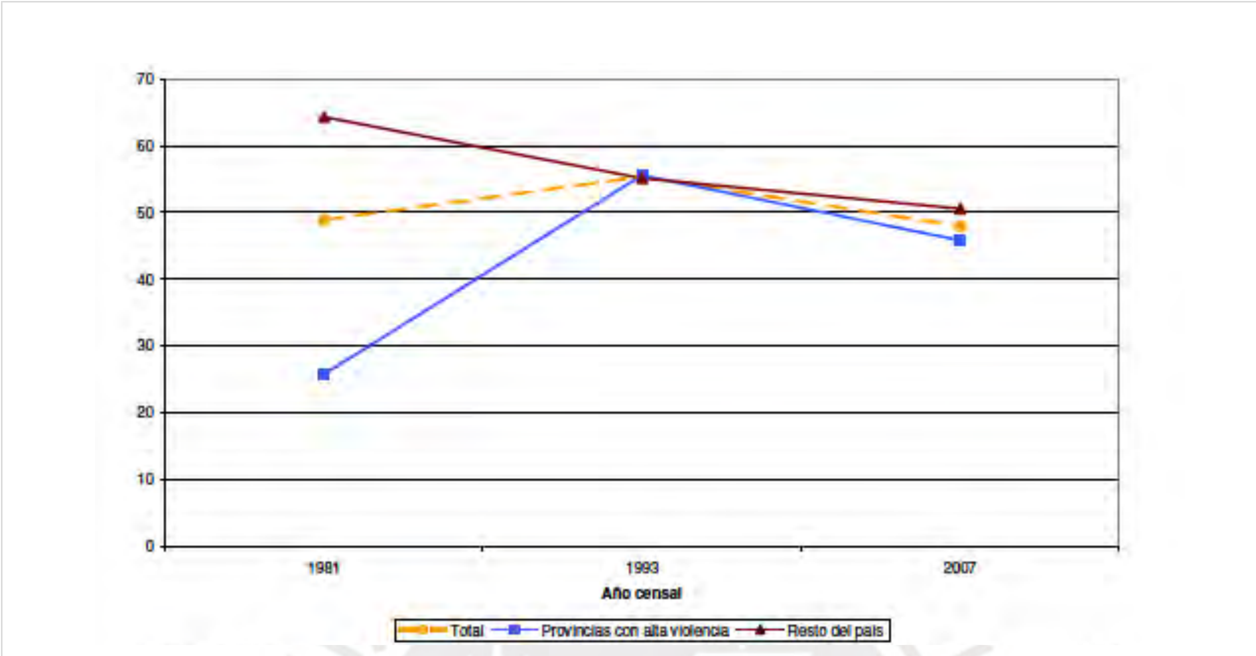


Figure 3.3. Outline of the model.

3.7.2 Appendix 2. Internal migration between 1981 and 2005.

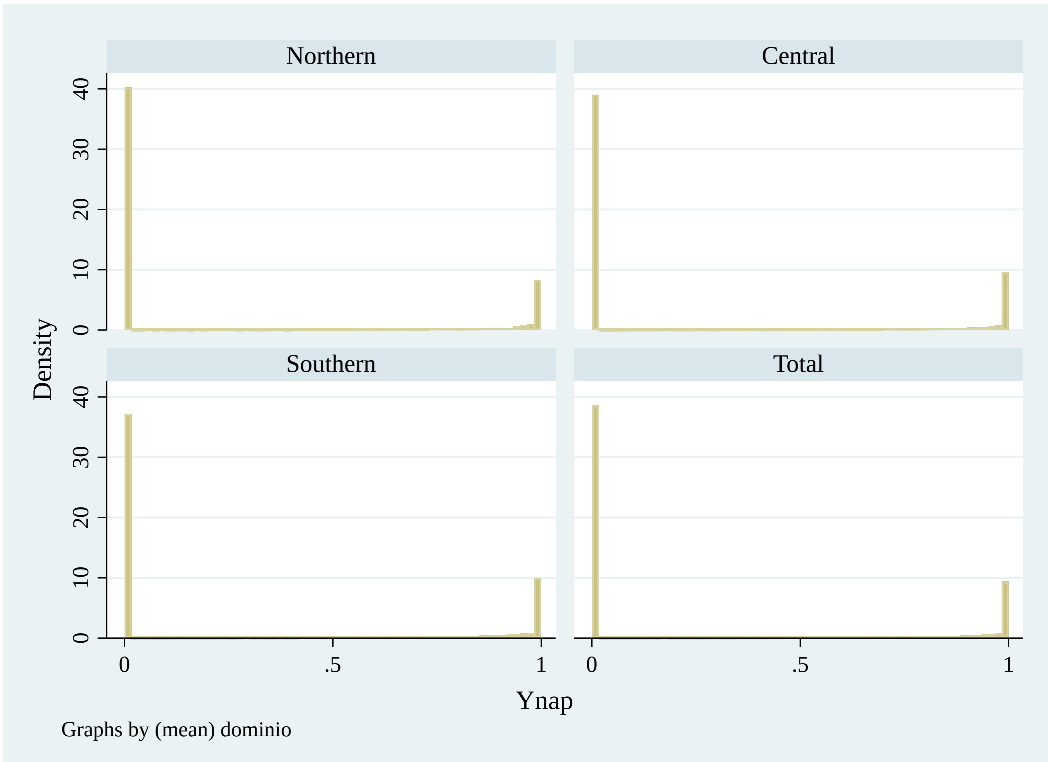


Internal migration between 1981 and 2005, by populations that were born in rural provinces (Table extracted from Ponce (2010: 39)).

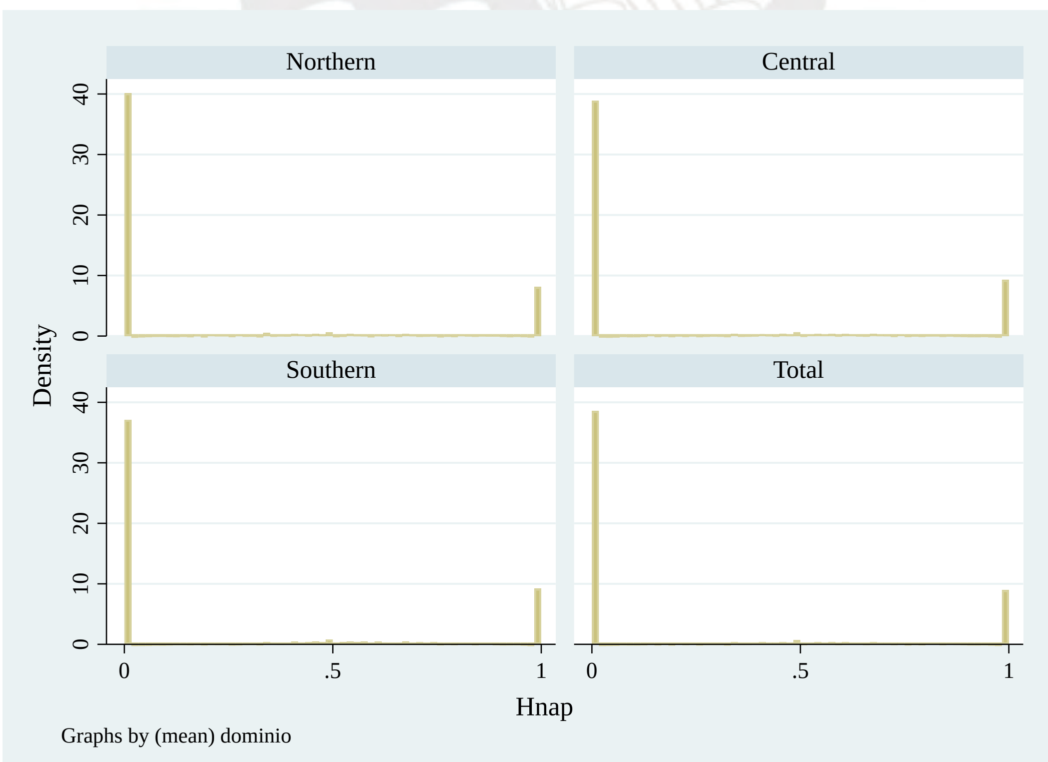
This graph shows the proportion of individuals that were born in rural provinces but live in a different province with respect to all individuals born in rural provinces. The blue line represents provinces with high violence during the internal conflict, the red line represents the low violence provinces, and the yellow line combines all provinces. Migration rates refer to the country population (Coast, Andean, and Amazon regions). However, given that there is no 1981 census information available for Loreto, San Martin, and Apurimac, the calculations of this graph excluded individuals living in these 3 departments. Source: Ponce (2010: 39).

3.7.3 Appendix 3. Complementary tables and figures.

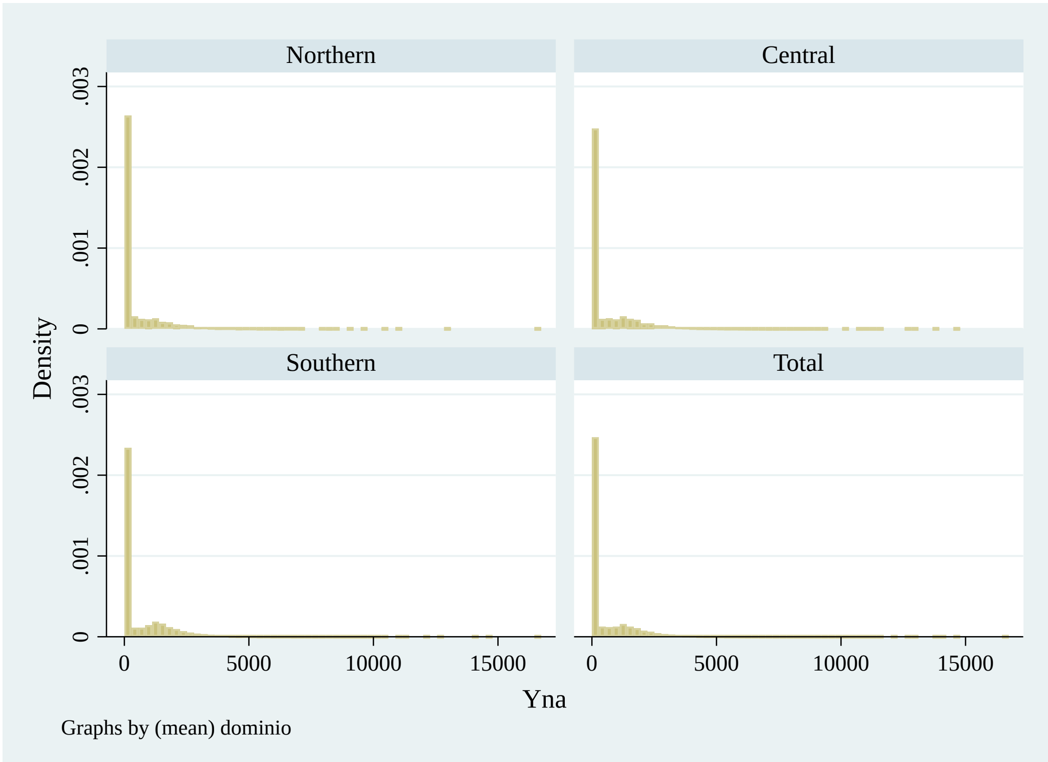
a. Non-farm income share



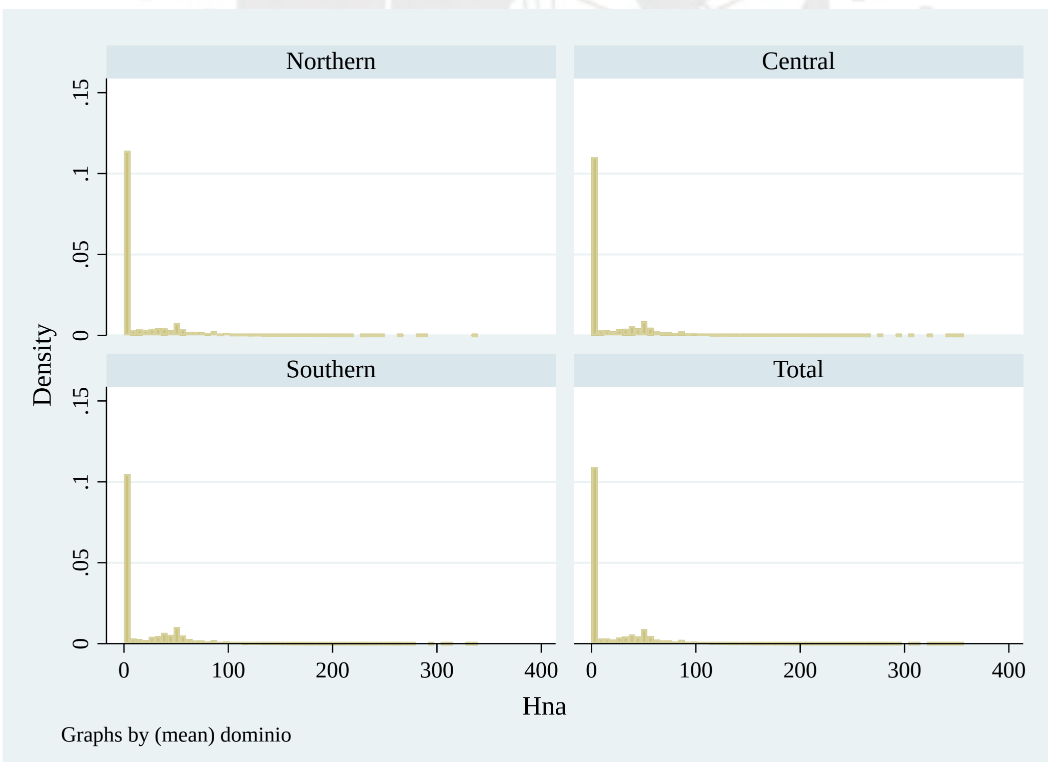
b. Non-farm working hours share



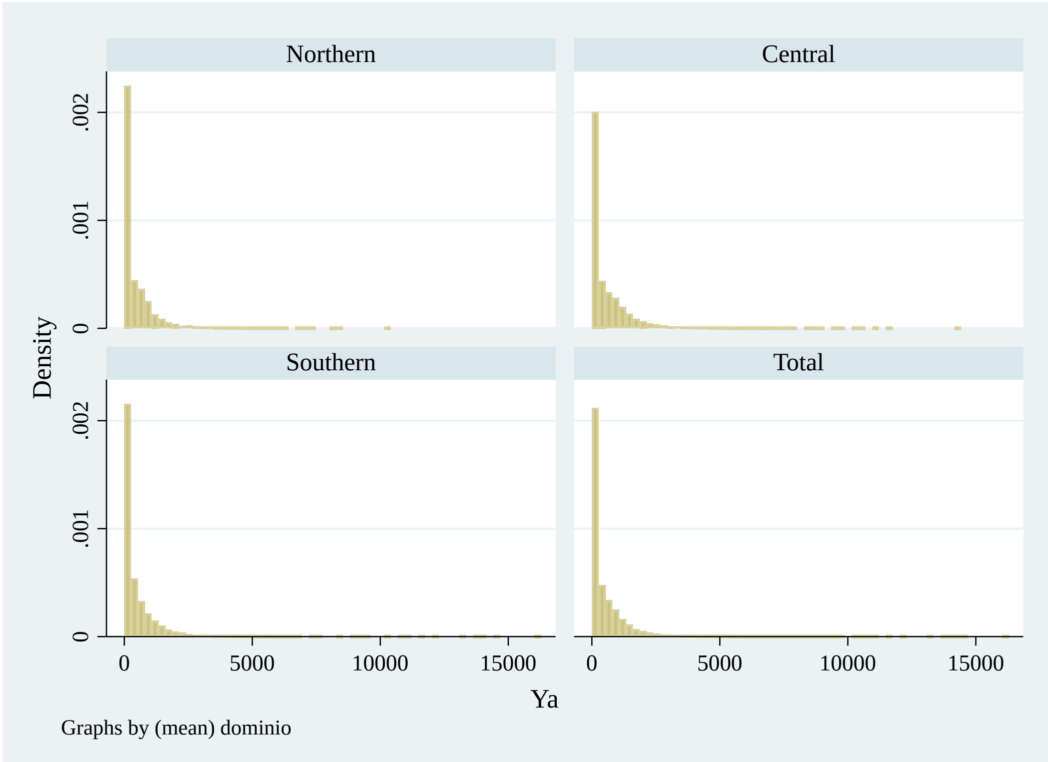
c. Non-farm Income



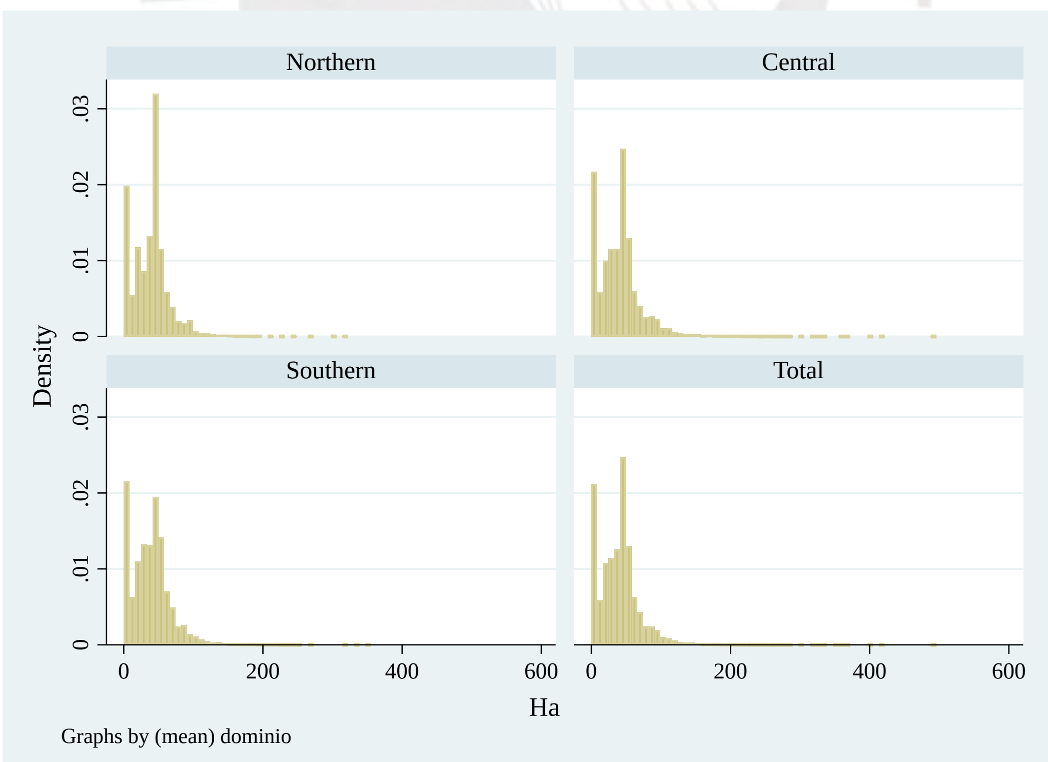
d. Number of non-farm working hours



e. Farm income



f. Farm working hours



g. Net labor income

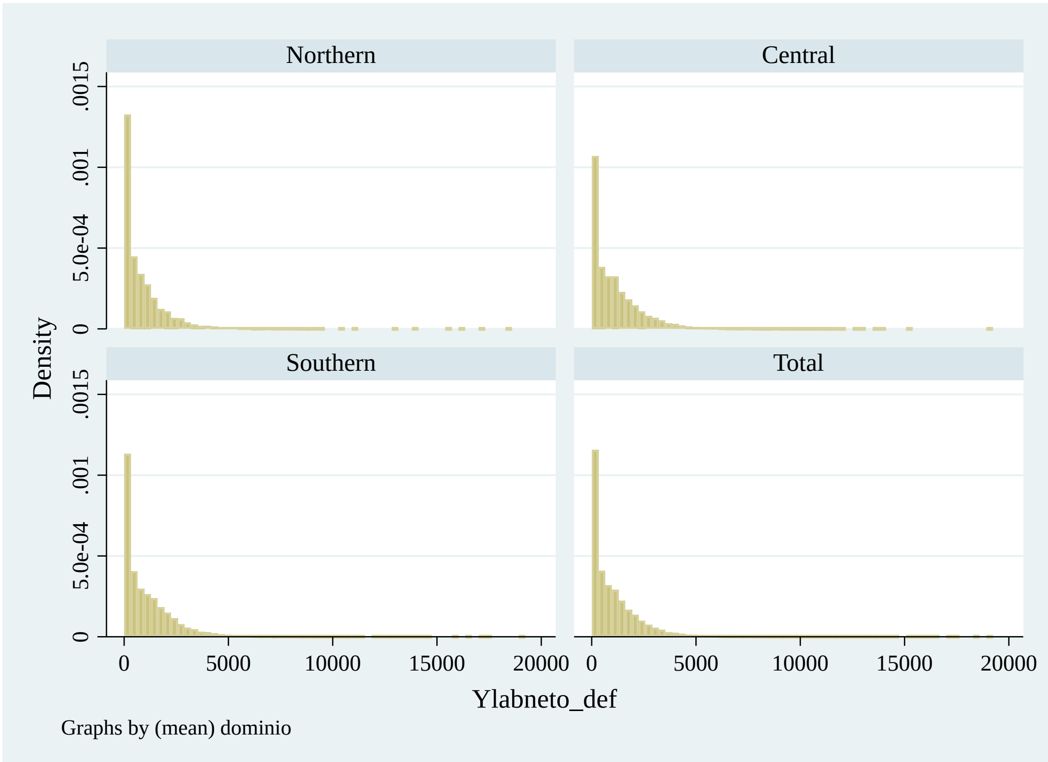


Figure 3.4. Histogram of outcome variables associated with household income diversification strategies.

Survey sample weights were used show a representative picture of each domain. Source: own estimates based on data from the 2014 EPHR.

Table 3.4. Unexpected climatic events.

Type of unexpected climatic event reported by the household	Andean region	Northern	Central	Southern
Hail *	42%	11%	41%	67%
Prolonged period of rain	20%	12%	21%	24%
Landslide (*huaicos* or *deslizamientos*)	4%	3%	7%	3%
Flood	2%	0%	1%	5%
Other events	13%	5%	12%	21%
No event	48%	79%	49%	23%

* It may include frost or a freezing event.

Source: own estimates based on data from the 2014 EPHR. Survey sample weights were used show a representative picture of each domain.

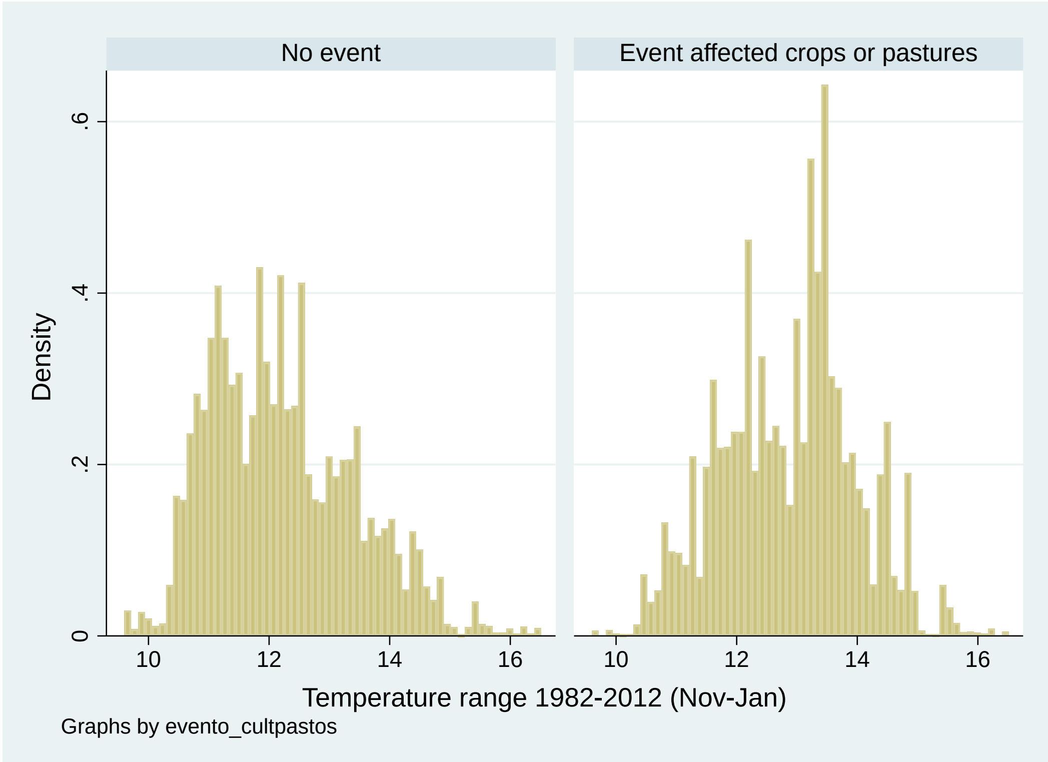
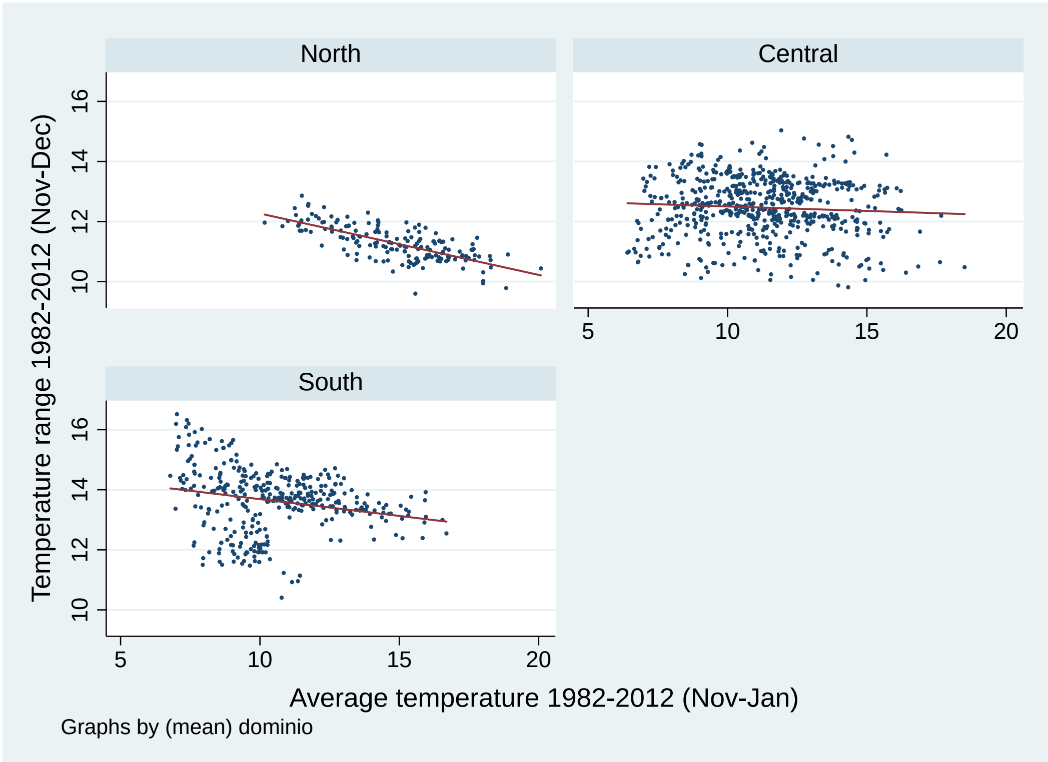


Figure 3.5. Temperature range in the district by groups of households with crops or pastures affected by an unexpected climatic event (hail, flood, landslide, or other).

Survey sample weights were used show a representative picture of each domain.
Source: own estimates based on data from the 2014 EPHR.

a. Temperature range and average temperature (Nov-Jan, 1982-2012).



b. Temperature range and average precipitation (Nov-Jan, 1982-2012).

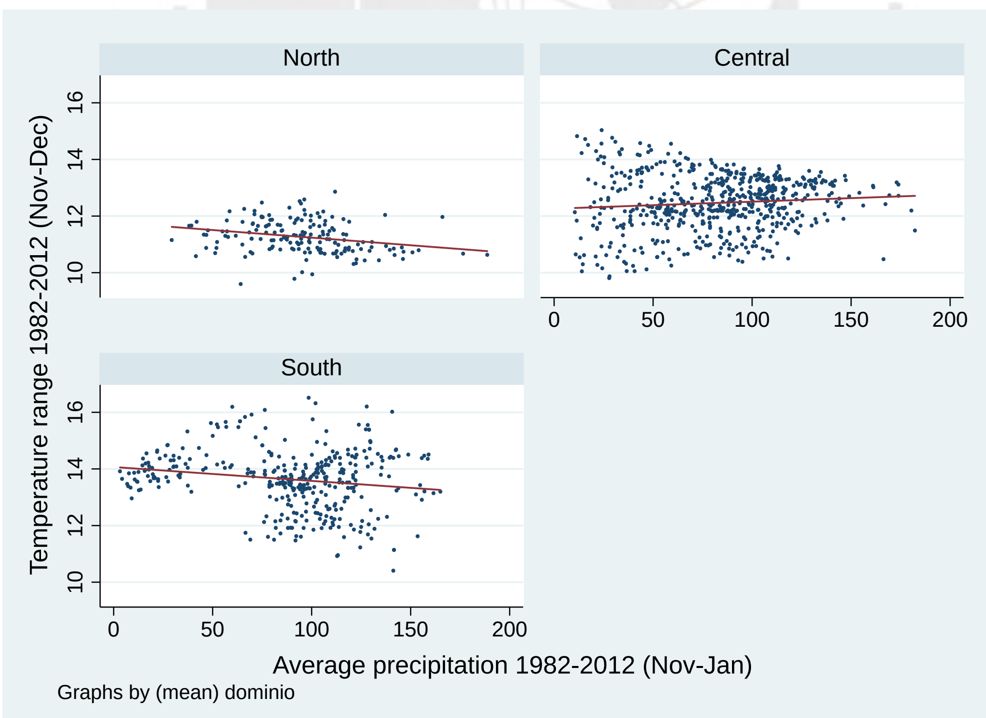


Figure 3.6. Correlation between climatic conditions. Each dot represents a district.

Source: Based on the estimates by Ponce, Arnillas and Escobal (2015).

Table 3.5. GLM average marginal effects on (i) non-farm labor income (levels) and (ii) non-farm working hours.

Covariates	Non-farm labor income (levels)			Working hours allocated to non-farm activities		
	Gamma, log North	Gamma, log Central	Gaussian, log South [iv]	Poisson, log North	Gamma, log Central	Gaussian, log South [v]
Single-headed household dummy	21.444	-26.786	-94.436***	2.363***	0.825	-0.938
	(38.529)	(24.312)	(21.379)	(0.888)	(0.777)	(0.686)
The mother tongue reported by household head and spouse is an indigenous language	97.966	-111.715***	-111.279***	8.498	-3.158***	-3.966***
	(140.243)	(28.983)	(37.251)	(6.502)	(0.860)	(1.217)
Age of the household head	-6.108***	-8.479***	-5.625***	-0.103***	-0.159***	-0.189***
	(1.028)	(0.779)	(0.680)	(0.026)	(0.023)	(0.022)
Dependency ratio (hh members [<14y,64y] / [14-64])	-119.575***	-162.407***	-159.946***	-4.544***	-4.137***	-5.257***
	(22.966)	(15.305)	(16.609)	(0.599)	(0.454)	(0.502)
Years of formal education of the most educated hh member	80.683***	99.671***	99.408***	2.331***	2.780***	2.463***
	(5.305)	(3.876)	(3.529)	(0.129)	(0.110)	(0.102)
Number of household members	29.685***	45.782***	60.624***	1.766***	1.577***	2.391***
	(7.323)	(5.069)	(4.752)	(0.219)	(0.156)	(0.142)
Strong distant ties - the household has strong family ties in a different province (at least one sibling or parent of the household head or spouse)	22.469	55.899***	6.116	2.078***	1.458**	1.068*
	(24.813)	(21.577)	(20.148)	(0.734)	(0.641)	(0.626)
Weak ties (% of households in the district with strong distant ties)	174.954	-59.549	447.977***	5.153	-1.768	17.732***
	(133.936)	(83.339)	(95.436)	(3.612)	(2.723)	(3.710)

Covariates	Non-farm labor income (levels)			Working hours allocated to non-farm activities		
	Gamma, log	Gamma, log	Gaussian, log	Poisson, log	Gamma, log	Gaussian, log
	North	Central	South [iv]	North	Central	South [v]
Local network - the household participates in an organization that can affect economic outcomes (political, governmental planning, productive or commercialization associations) ii	-117.067***	-54.176*	-38.244	-3.926***	-2.506***	-0.894
	(37.262)	(29.907)	(27.086)	(1.041)	(0.875)	(0.790)
The household has a second dwelling that it visits frequently	173.255***	110.637***	103.697***	2.799**	3.428***	3.281***
	(53.510)	(33.413)	(26.096)	(1.327)	(0.993)	(0.811)
Access to financial services	41.196	143.399***	238.401***	-0.538	2.111***	4.965***
	(32.681)	(26.840)	(24.758)	(0.858)	(0.758)	(0.798)
Land size (Owns)	-0.030*	0.017	-0.022	-0.002***	0.000	-0.001*
	(0.018)	(0.022)	(0.015)	(0.001)	(0.001)	(0.001)
Unexpected climate events in the district (% of farmers in the district who had crops or pastures affected by an unexpected climate event during the previous year)	-0.613	-98.368	28.675	5.896	-3.272*	0.084
	(112.154)	(62.398)	(79.678)	(3.606)	(1.965)	(2.820)
30-year average temperature (Nov/Dec/Jan)	-0.079	9.621	7.504	0.431	-0.088	-0.157
	(15.935)	(11.406)	(9.314)	(0.491)	(0.349)	(0.304)
30-year temperature range (Nov/Dec/Jan)	127.342**	52.876***	4.143	4.137***	1.806***	0.198
	(55.797)	(17.984)	(23.575)	(1.576)	(0.592)	(0.706)
30-year average precipitation (Nov/Dec/Jan)	2.281**	-0.032	-0.525	0.088***	-0.003	0.006
	(1.031)	(0.750)	(0.626)	(0.030)	(0.024)	(0.021)
Percentage of farmers with irrigation systems (gravity or technified) in the district	-67.452	-120.586**	-67.142	2.292	-3.623*	-3.217
	(119.445)	(58.528)	(61.694)	(3.904)	(1.853)	(2.112)
Land Gini coefficient (equivalent hectares)	904.767**	694.469***	96.974	29.870***	21.140***	-0.702
	(358.789)	(170.640)	(165.162)	(9.281)	(5.405)	(5.495)

Covariates	Non-farm labor income (levels)			Working hours allocated to non-farm activities		
	Gamma, log	Gamma, log	Gaussian, log	Poisson, log	Gamma, log	Gaussian, log
	North	Central	South [iv]	North	Central	South [v]
Product market - Proportion of farmers that allocate most yield from at least one plot to markets	-361.405***	-88.656	348.028***	-16.650***	-3.223	12.713***
	(109.980)	(67.675)	(74.619)	(3.775)	(2.229)	(2.615)
Non-agricultural sector – median hourly income in the province of residence	-4.056	6.764*	7.295*	-0.403**	-0.343***	-0.291**
	(5.480)	(3.846)	(4.426)	(0.166)	(0.119)	(0.141)
Agricultural sector – median hourly income in the province of residence	4.221	2.603	-18.733***	-0.300	0.082	-0.617***
	(8.279)	(4.097)	(3.164)	(0.242)	(0.127)	(0.105)
% of households with access to safe water	69.057	335.965***	354.950***	7.440**	11.426***	10.819***
	(113.666)	(70.456)	(88.593)	(3.722)	(2.137)	(3.007)
The province experienced high violence during the internal conflict (1980's, 1990's) iii	-89.802**	3.772	-36.351	-5.035***	1.251	-2.669
	(42.959)	(38.890)	(57.656)	(1.248)	(1.162)	(2.187)
Observations	12,060	29,345	21,860	12,060	29,345	21,860

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. The estimates were adjusted by the sample design (stratified and clustered random sample).

[i] Real income was spatially deflated using the poverty line (ENAHO 2014).

[ii] This excludes other associations such as those focused on cultural and sports activities, health, school or collective food and meals programs.

[iii] Classification by Ponce (2010: 81-82) based on information gathered by the Truth and Reconciliation Commission (2003) for the period 1980-2000.

[iv] Column in gray: these results are not robust, since we failed to reject the null hypothesis that this model specification is correct (pv=0.003).

[v] Column in gray: these results are not robust, since we failed to reject the null hypothesis that this model specification is correct (pv=0.002).

Source: own estimates based on data from the 2014 EPHR, 2012 Census of Agriculture, identification of provinces that experienced high violence during the internal war by Ponce (2010), and climate estimates by Ponce, Arnillas and Escobal (2015).

Table 3.6. GLM average marginal effects on (i) Farm labor income (levels) and (ii) Farm working hours.

Covariates	Farm labor income (levels)			Working hours allocated to Farm activities		
	Gamma, log	Gamma, log	Gamma, log	Gaussian, log	Gaussian, log	Gaussian, identity
	North	Central [iv]	South	North	Central	South
Single-headed household dummy	-66.969***	-78.423***	-105.946***	-5.504***	-4.430***	-3.925***
	(17.068)	(13.146)	(13.352)	(0.817)	(0.602)	(0.543)
The mother tongue reported by household head and spouse is an indigenous language	-219.404***	11.921	30.105	-9.130***	0.427	4.261***
	(33.830)	(18.619)	(36.482)	(1.924)	(0.834)	(1.229)
Age of the household head	0.411	-1.028**	1.639***	0.085***	0.136***	0.213***
	(0.530)	(0.430)	(0.496)	(0.019)	(0.018)	(0.020)
Dependency ratio (hh members [<14y,64y] / [14-64])	-85.493***	-121.431***	-81.875***	-6.932***	-7.689***	-5.621***
	(11.934)	(9.049)	(8.770)	(0.550)	(0.381)	(0.337)
Years of formal education of the most educated hh member	-2.974	-3.256	5.843***	-1.119***	-1.182***	-0.713***
	(2.626)	(2.106)	(2.003)	(0.119)	(0.072)	(0.077)
Number of household members	56.328***	84.025***	54.305***	3.836***	4.418***	3.547***
	(4.703)	(4.046)	(4.574)	(0.255)	(0.164)	(0.222)
Strong distant ties - the household has strong family ties in a different province (at least one sibling or parent of the household head or spouse)	22.988	-7.345	-12.475	-0.568	-0.253	-1.195*
	(16.200)	(14.696)	(15.262)	(0.731)	(0.539)	(0.648)
Weak ties (% of households in the district with strong distant ties)	159.741**	-113.654*	-38.512	-6.275**	-6.420**	-9.147***
	(75.506)	(63.789)	(78.300)	(3.161)	(2.732)	(3.320)

Covariates	Farm labor income (levels)			Working hours allocated to Farm activities		
	Gamma, log	Gamma, log	Gamma, log	Gaussian, log	Gaussian, log	Gaussian, identity
	North	Central [iv]	South	North	Central	South
Local network - the household participates in an organization that can affect economic outcomes (political, governmental planning, productive or commercialization associations) ii	61.890**	46.197**	65.735**	1.232	0.768	2.478***
	(29.084)	(23.549)	(25.627)	(1.036)	(0.856)	(0.823)
The household has a second dwelling that it visits frequently	59.659*	60.315***	71.307***	-2.843***	-0.654	0.275
	(35.356)	(21.981)	(26.538)	(0.941)	(0.860)	(0.834)
Access to financial services	29.383	-54.083***	-37.235	1.584**	-3.220***	-4.205***
	(19.982)	(16.591)	(25.297)	(0.761)	(0.641)	(0.829)
Land size (Owns)	-0.006	-0.002	0.047***	0.001*	0.000	0.001***
	(0.008)	(0.009)	(0.012)	(0.000)	(0.000)	(0.000)
Unexpected climate events in the district (% of farmers in the district who had crops or pastures affected by an unexpected climate event during the previous year)	28.669	10.361	129.282**	2.656	1.352	-2.477
	(74.649)	(45.571)	(54.726)	(3.069)	(1.978)	(2.439)
30-year average temperature (Nov/Dec/Jan)	-34.980***	13.435**	5.831	-0.092	0.094	-0.644**
	(10.583)	(5.998)	(7.255)	(0.330)	(0.304)	(0.288)
30-year temperature range (Nov/Dec/Jan)	-167.602***	-15.188	8.315	-6.763***	-1.768***	1.586***
	(41.395)	(13.613)	(14.550)	(1.520)	(0.498)	(0.587)
30-year average precipitation (Nov/Dec/Jan)	0.875	-0.390	-1.420***	-0.040**	-0.056**	0.004
	(0.587)	(0.419)	(0.494)	(0.018)	(0.022)	(0.021)
Percentage of farmers with irrigation systems (gravity or technified) in the district	85.752	135.309***	-15.560	3.722	6.075***	0.731
	(63.900)	(40.847)	(49.954)	(2.714)	(1.588)	(2.006)
Land Gini coefficient (equivalent hectares)	-447.098**	-117.085	-619.257***	-37.611***	-21.659***	-20.209***
	(193.306)	(99.731)	(127.204)	(8.096)	(3.944)	(5.101)

Covariates	Farm labor income (levels)			Working hours allocated to Farm activities		
	Gamma, log	Gamma, log	Gamma, log	Gaussian, log	Gaussian, log	Gaussian, identity
	North	Central [iv]	South	North	Central	South
Product market - Proportion of farmers that allocate most yield from at least one plot to markets	159.369***	174.744***	0.909	6.942***	7.827***	-3.466
	(56.993)	(48.460)	(65.004)	(2.139)	(1.970)	(2.485)
Non-agricultural sector – median hourly income in the province of residence	5.077*	8.658***	4.250	0.207*	0.016	-0.012
	(3.016)	(2.555)	(3.186)	(0.121)	(0.101)	(0.126)
Agricultural sector – median hourly income in the province of residence	49.994***	33.728***	26.690***	0.619***	-0.065	0.222*
	(4.783)	(2.706)	(3.064)	(0.204)	(0.095)	(0.127)
% of households with access to safe water	-41.934	2.930	31.325	-11.437***	-2.272	-5.006*
	(81.169)	(45.607)	(73.519)	(3.547)	(1.858)	(3.027)
The province experienced high violence during the internal conflict (1980's, 1990's) iii	23.951	58.561**	-51.306	1.636	4.573***	-1.355
	(30.779)	(27.216)	(43.209)	(1.161)	(1.150)	(1.702)
Observations	12,060	29,345	21,860	12,060	29,345	21,860

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. The estimates were adjusted by the sample design (stratified and clustered random sample).

[i] Real income was spatially deflated using the poverty line (ENAHO 2014).

[ii] This excludes other associations such as those focused on cultural and sports activities, health, school or collective food and meals programs.

[iii] Classification by Ponce (2010: 81-82) based on information gathered by the Truth and Reconciliation Commission (2003) for the period 1980-2000.

[iv] Column in gray: these results are not robust, since we failed to reject the null hypothesis that this model specification is correct (pv=0.008).

Source: own estimates based on data from the 2014 EPHR, 2012 Census of Agriculture, identification of provinces that experienced high violence during the internal war by Ponce (2010), and climate estimates by Ponce, Arnillas and Escobal (2015).

Table 3.7. GLM average marginal effects on Family Labor Income (net).

Covariates	Gamma, log North	Poisson, log Central	Poisson, log South
Single-headed household dummy	-60.861**	-84.769***	-189.927***
	(28.438)	(18.570)	(20.442)
The mother tongue reported by household head and spouse is an indigenous language	-88.974	-115.280***	-179.229***
	(83.736)	(24.961)	(45.449)
Age of the household head	-3.573***	-4.582***	-4.670***
	(0.809)	(0.641)	(0.641)
Dependency ratio (hh members [<14y,64y] / [14-64])	-178.951***	-269.790***	-241.488***
	(16.996)	(14.010)	(14.508)
Years of formal education of the most educated hh member	74.659***	94.309***	91.753***
	(4.120)	(2.926)	(3.252)
Number of household members	80.999***	108.854***	105.533***
	(6.937)	(4.838)	(5.551)
Strong distant ties - the household has strong family ties in a different province (at least one sibling or parent of the household head or spouse)	55.358**	27.811	20.248
	(24.401)	(18.183)	(21.720)
Weak ties (% of households in the district with strong distant ties)	389.441***	-104.064	394.417***
	(121.750)	(69.533)	(111.327)
Local network - the household participates in an organization that can affect economic outcomes (political, governmental planning, productive or commercialization associations) ii	-30.799	-20.871	40.456
	(39.109)	(26.302)	(35.810)
The household has a second dwelling that it visits frequently	176.742***	154.232***	173.803***
	(49.723)	(28.352)	(30.090)
Access to financial services	58.437*	184.811***	272.509***
	(30.970)	(22.452)	(30.185)
Land size (Owns)	-0.039***	-0.011	0.033**
	(0.015)	(0.014)	(0.015)
Unexpected climate events in the district (% of farmers in the district who had crops or pastures affected by an unexpected climate event during the previous year)	58.893	-80.134	197.618**
	(136.265)	(55.986)	(83.633)

Covariates	Gamma, log North	Poisson, log Central	Poisson, log South
30-year average temperature (Nov/Dec/Jan)	-18.601	23.500**	5.959
	(16.088)	(11.120)	(9.825)
30-year temperature range (Nov/Dec/Jan)	38.218	20.330	4.013
	(56.512)	(16.556)	(21.514)
30-year average precipitation (Nov/Dec/Jan)	2.849***	-0.436	-1.636**
	(1.033)	(0.691)	(0.713)
Percentage of farmers with irrigation systems (gravity or technified) in the district	-79.521	10.070	-96.786
	(112.668)	(49.874)	(62.538)
Land Gini coefficient (equivalent hectares)	173.422	478.786***	-393.963**
	(318.379)	(158.219)	(177.099)
Product market - Proportion of farmers that allocate most yield from at least one plot to markets	-149.799	83.457	396.880***
	(100.625)	(64.222)	(85.481)
Non-agricultural sector – median hourly income in the province of residence	11.611**	15.809***	16.559***
	(5.009)	(3.253)	(4.634)
Agricultural sector – median hourly income in the province of residence	49.296***	25.775***	1.779
	(6.928)	(3.502)	(3.730)
% of households with access to safe water	129.285	455.572***	514.016***
	(109.528)	(58.546)	(98.323)
The province experienced high violence during the internal conflict (1980's, 1990's) iii	-117.196***	113.911***	-82.337
	(44.402)	(32.965)	(63.458)
Observations	12,060	29,345	21,860

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1. The estimates were adjusted by the sample design (stratified and clustered random sample).

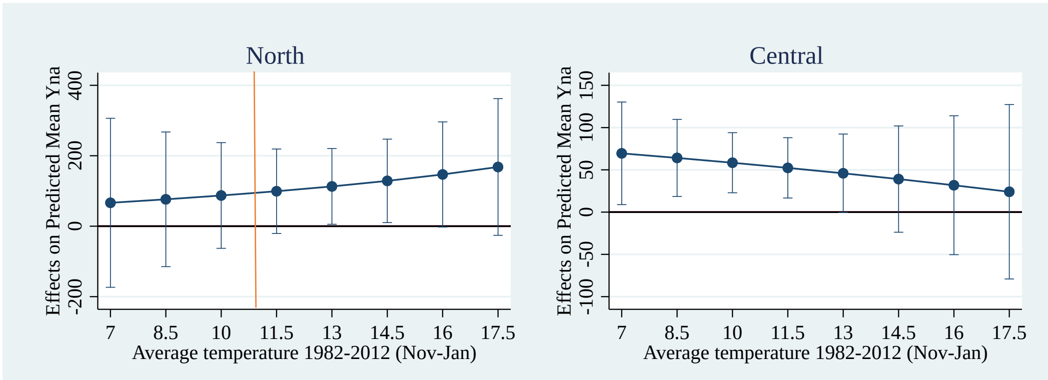
[i] Real income was spatially deflated using the poverty line (ENAHO 2014).

[ii] This excludes other associations such as those focused on cultural and sports activities, health, school or collective food and meals programs.

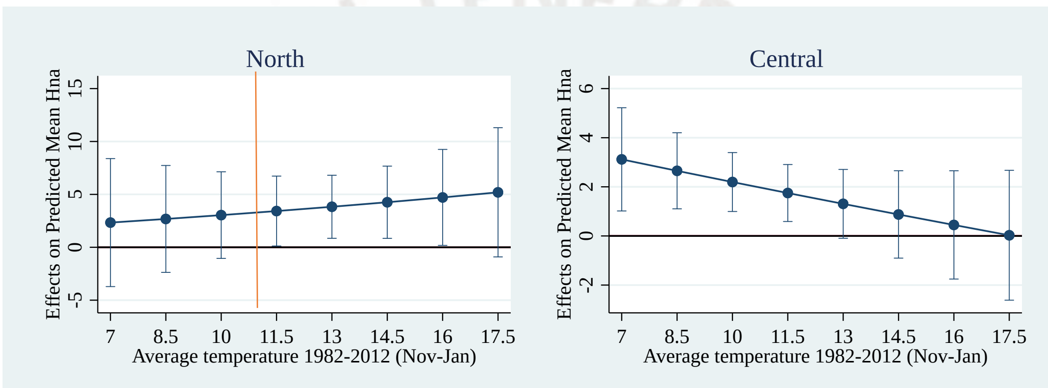
[iii] Classification by Ponce (2010: 81-82) based on information gathered by the Truth and Reconciliation Commission (2003) for the period 1980-2000.

Source: own estimates based on data from the 2014 EPHR, 2012 Census of Agriculture, identification of provinces that experienced high violence during the internal war by Ponce (2010), and climate estimates by Ponce, Arnillas and Escobal (2015).

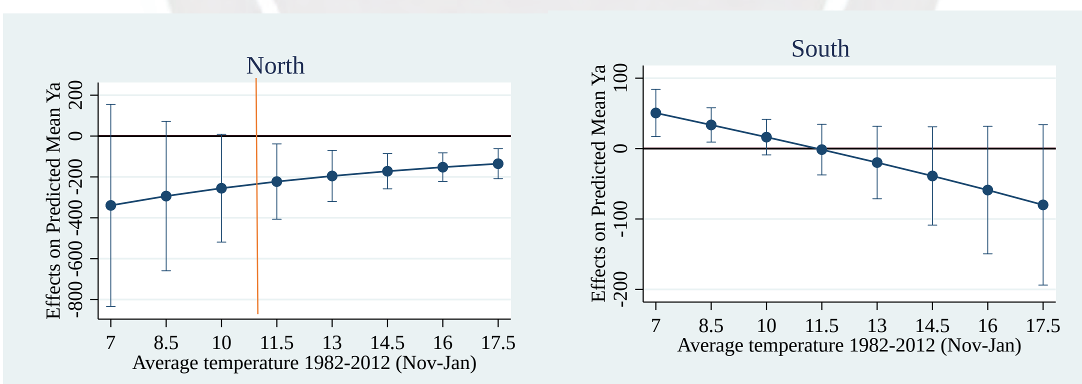
a. Non-Farm Income (level).



b. Non-Farm Working Hours.



c. Farm Income (level)



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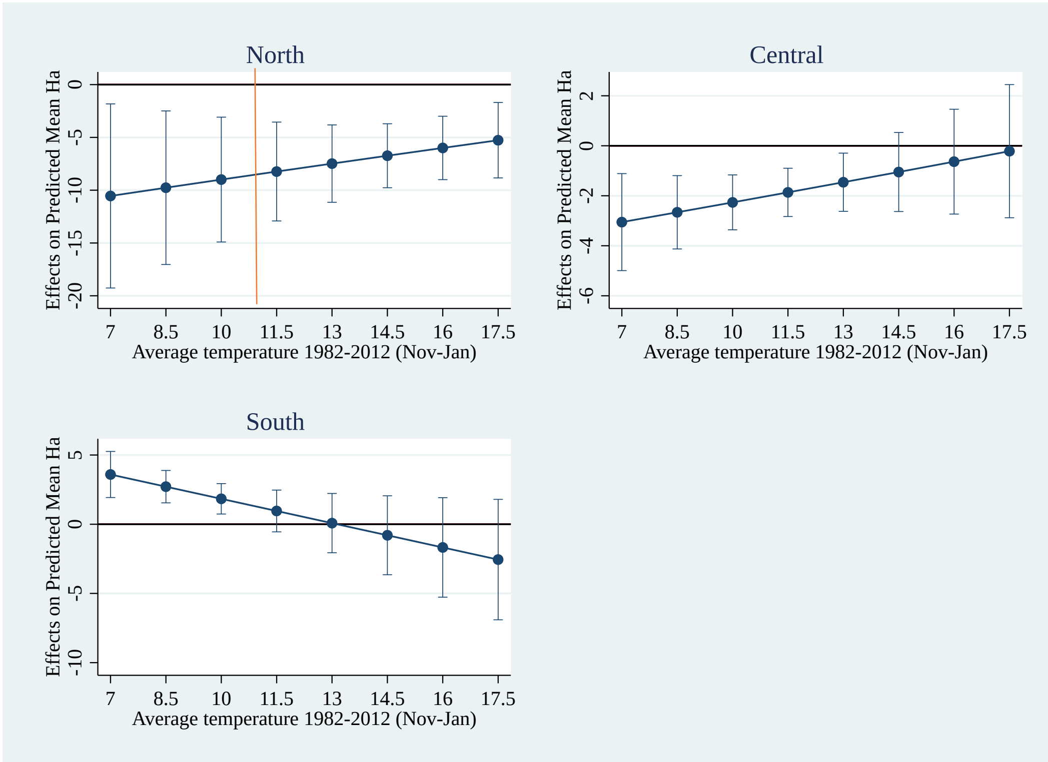
d. Farm Working Hours



e. Labor Income (level)

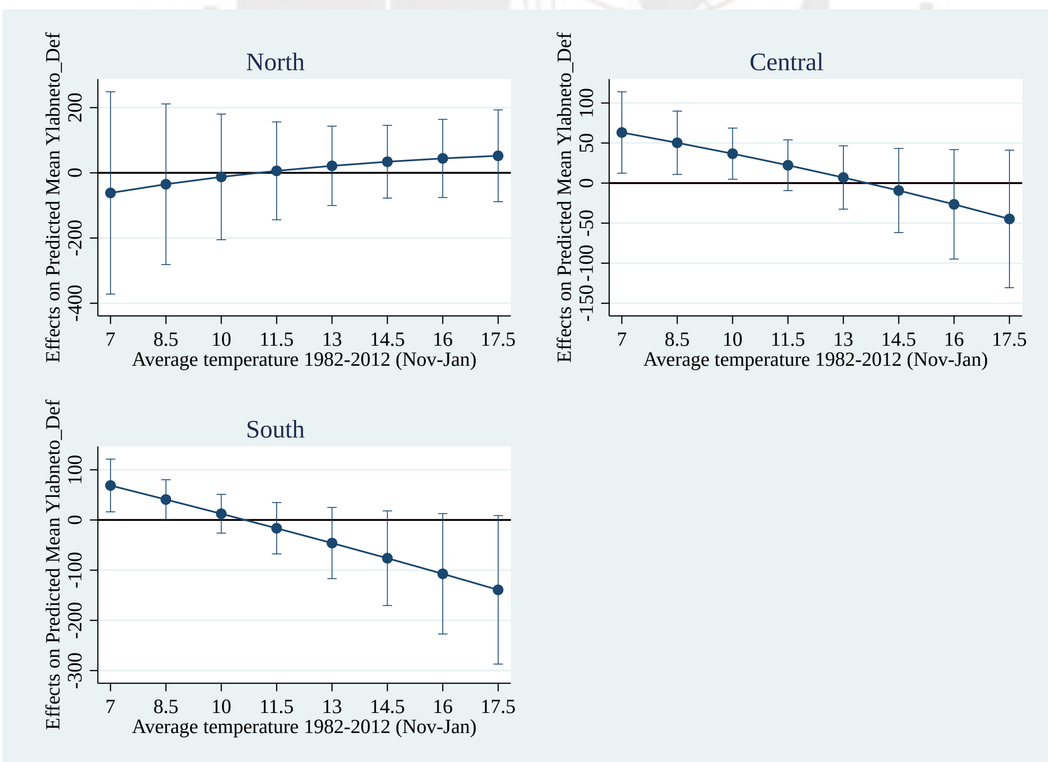


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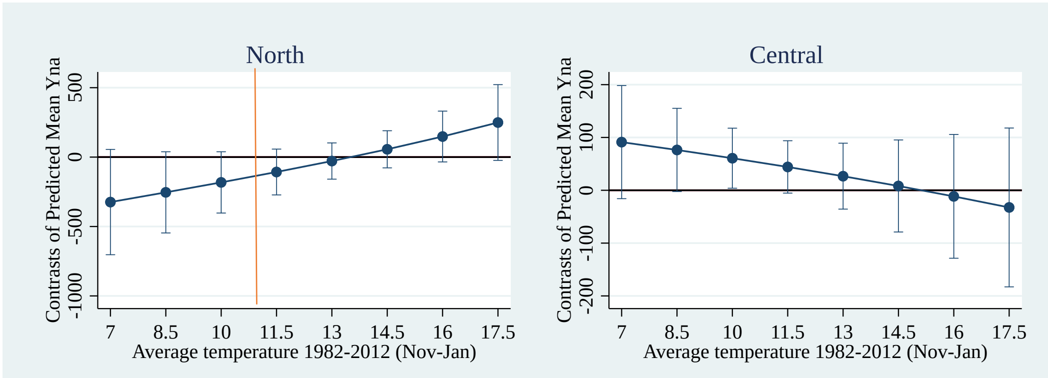
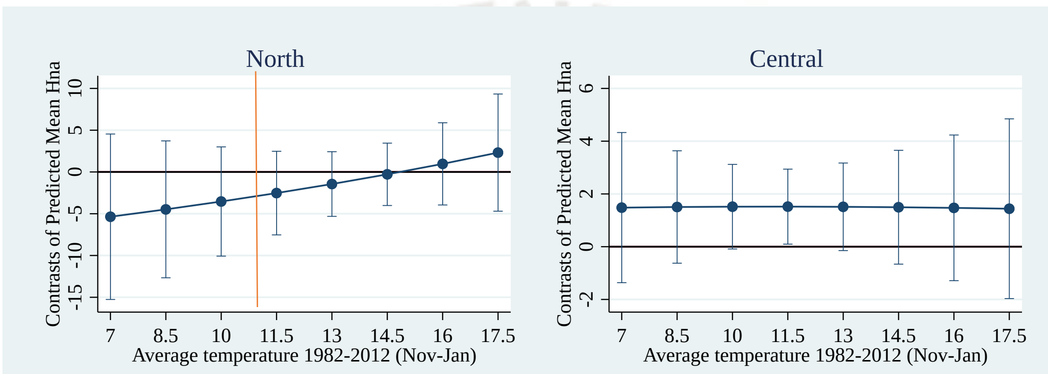
Figure 3.7. Effect of intra-seasonal climate variability on income diversification strategies (farm/non-farm working hours and income levels) in the Andean region, by mean temperature.

The figure shows the average marginal effect of temperature range on each outcome, setting mean temperatures at specific values. Due to low prevalence of mean temperatures below 11˚C in the northern domain (Figure 3.9), only results above that threshold should be considered. Parameters were independently estimated for each domain using generalized linear models with distributional families and link functions specified in Table 3.5, Table 3.6 and Table 3.7. . Models with specification problems (see table footnotes) are not included.

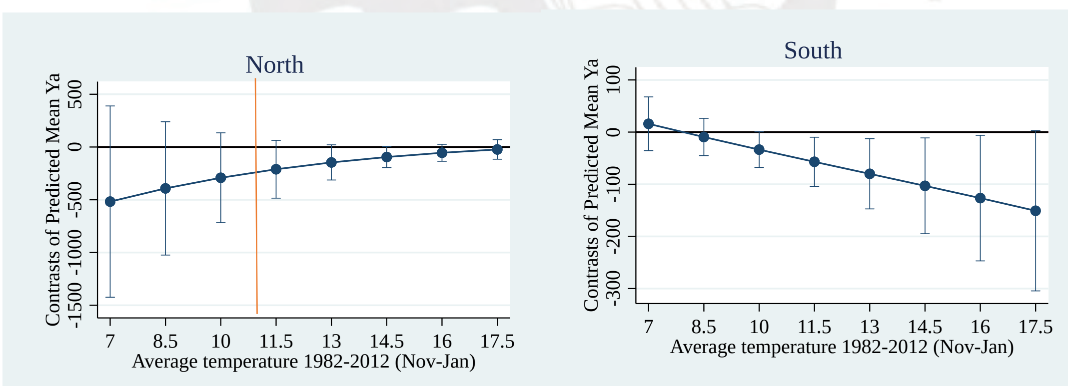
a. Non-Farm Income (level)



b. Non-Farm working hours.

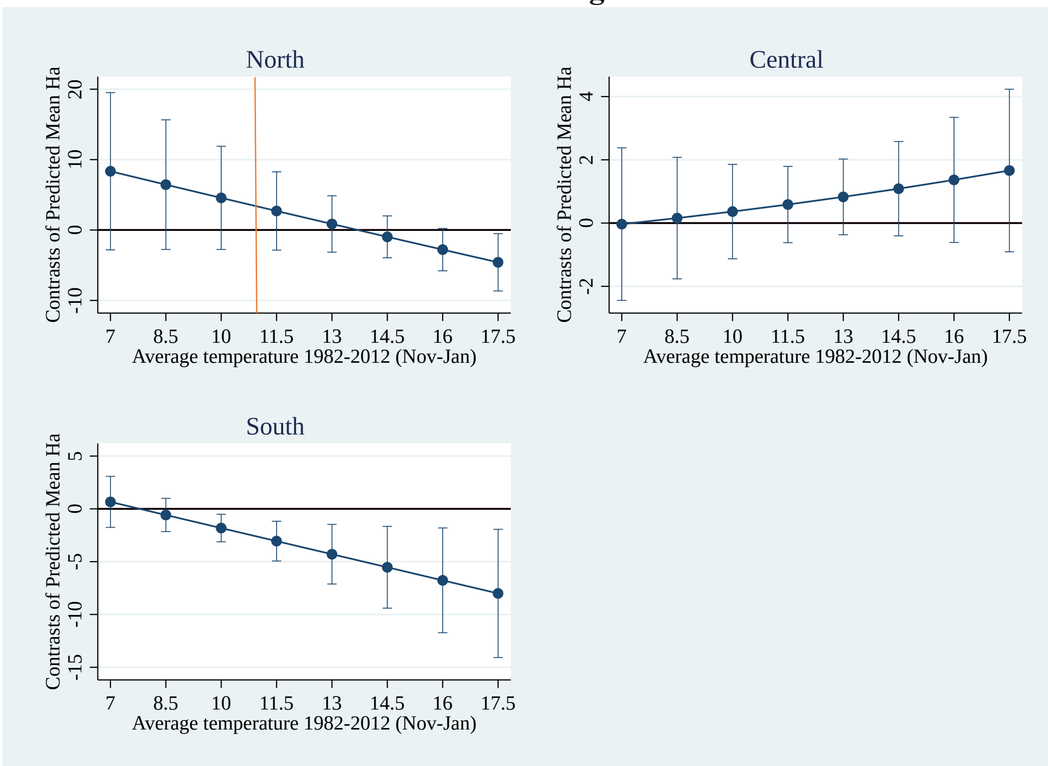


c. Farm Income (level)

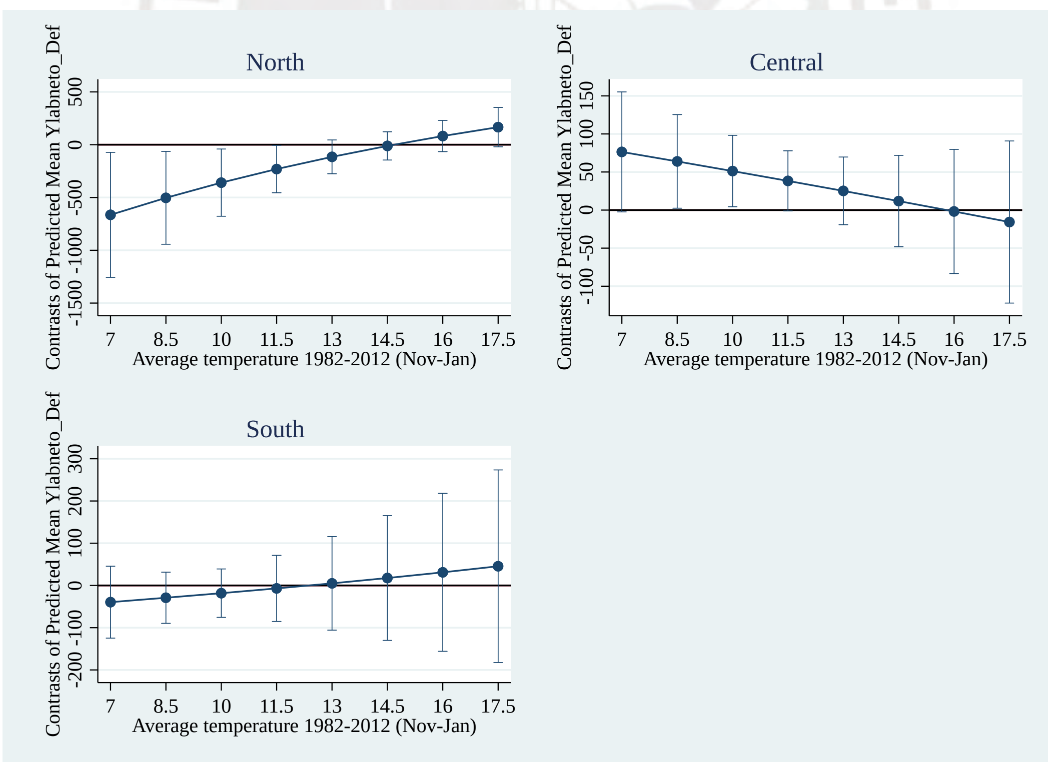


(continues in the next page…)

d. Farm Working Hours



e. Labor Income (level)



(continues in the next page…)

Figure 3.8. The role of distant, strong ties in household adaptation to climate variability. Contrast between the effect intra-seasonal of climate variability on income diversification strategies for households with and without distant, strong ties, by mean temperature.

These figures show the statistical significance of the difference between the responses of the two types of households. Horizontal lines show the confidence interval of the point estimate for each mean temperature value. Due to low prevalence of mean temperatures below 11˚C in the northern domain (Figure 3.9), only results above that threshold should be considered. Parameters were independently estimated for each domain using generalized linear models with distributional families and link functions specified in Table 3.5, Table 3.6 and Table 3.7. . Models with specification problems (see table footnotes) are not included. Due to low prevalence of mean temperatures below 11˚C in the northern domain (Figure 3.9), only results above that threshold should be considered.

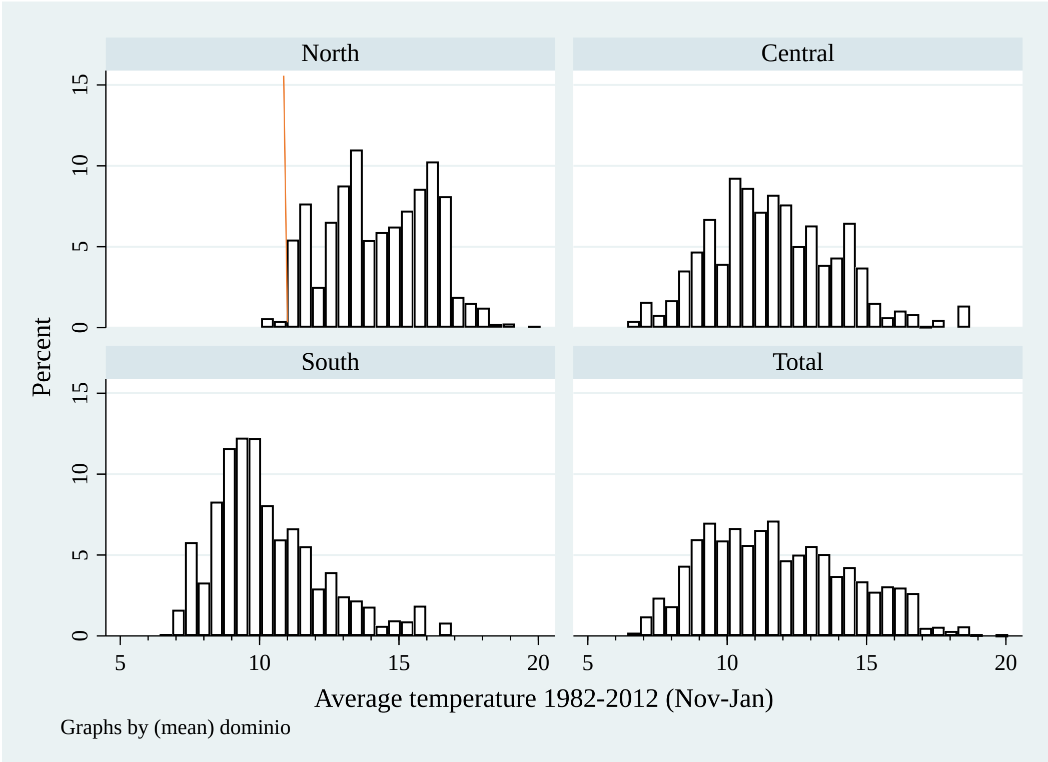


Figure 3.9. Distribution of households across the temperature gradient. Percentage of Andean households living in areas with (30-year average) mean temperatures.

Each bar represents the (weighted) percentage of households in the domain that live in districts with that mean temperature. Source: Climate data was estimated by Ponce, Arnillas and Escobal (2015). Household data (weights) comes from EPHR 2014.

4 Conclusions

Household adaptive capacity depend not only on the assets and abilities of its members and the contribution of their networks, but also on broader environmental features that limit or enhance such adaptive capacity. Given that the Northern, Central and Southern sub-regions differ in topography and climate patterns, labor and land market dynamics, regional connectivity and access to larger markets, and institutional arrangements to access and control natural resources, among other factors, this thesis hypothesized that such sub-regional differences would play a role in household adaptation strategies. Both studies of this thesis find evidence of heterogeneous adaptation strategies across subregions.

As previously mentioned, climate risk depends not only on the probability of occurrence of a hazardous event but also on the impact that such event could have on household crops and other economic outcomes. If we consider a mild increase in climate variability in colder areas (which face mean temperatures closer to 0˚C), ceteris paribus, it is reasonable to expect that such an increase affects crops substantially more than it would in warmer areas (one could experience crop loss while the other may experience a decreased yield). To find out whether this was the case, both studies tested whether household adaptation strategies differ across the mean temperature gradient. Reviewing each study results separately gives the impression that this is not always the case. However, when putting both studies together, there's clearly a more significant response among households in colder areas, regardless of the sub-region of residence. Rural households in Northern and Central areas respond to higher climate variability by increasing their relative involvement in non-farm activities (working hours and income shares), and no response is observed in crop portfolio decisions. This response is significantly larger in colder areas. It is noteworthy that all robust estimates[60] show an increase in non-farm income levels and hours and a decrease in farm income levels and hours in these sub-regions.

In contrast, in Southern areas (more indigenous and isolated) the response to higher climate variability seems to be focused on farm activities. The first study finds evidence that households adapt crop diversification decisions to increases in climate variability in the coldest areas of the South (mean temperatures below 11˚C) by concentrating their portfolios into more tolerant crops and decreasing intercropping. The second study, on the other hand, finds no response in household

[60] As mentioned in Chapter 3, the results from the farm income level model for the Central sub-region are excluded due to specification issues.

non-farm income and working hours shares. More importantly, the study finds that Southern households respond to higher climate variability by working more hours on farm activities with no additional farm income, suggesting a lower farm productivity. These results suggest that crop portfolio adjustments are a fall back adaptation strategy amid adverse changing conditions (more than an optimal adaptation). Furthermore, given that crop diversification fosters resilience in agricultural systems, adaptation to higher climate variability involving more concentrated crop portfolios with reduced intercropping raises concern about potential threats to farm sustainability amid climate change. These results, especially the decrease in intercropping (a farm practice that requires information and assistance to identify the crop mix that can be used under new climate conditions), suggest that information and technical assistance is needed to improve household adaptive capacity.

Finally, the second study finds that distant, strong ties facilitate household adaptation to increasing climate variability in the Central and Southern Andes. Despite three models had specification issues (non-farm hours and income levels for the South and farm income levels for the Central Andes), the study finds sufficient evidence that distant, strong ties facilitate non-farm economic opportunities among households in the colder areas of the Central Andes (<13˚C), both in terms of non-farm working hours and income (shares and levels[61]). Interestingly, among Southern households it is in warmer areas (>11˚C) where distant, strong ties facilitate non-farm income opportunities (according to non-farm hours and income shares models). The results indicate that households with distant, strong ties adapt to climate variability by allocating less time to- and obtain less income from- farm activities than their peers, but with no consequence in net labor income. This suggests that non-farm income opportunities are facilitated by family living in distant areas. These results suggest that interventions aimed at increasing economic opportunities for rural households could benefit from information and communication technologies and other resources that enhance households' ability to capitalize on their spatially distant networks.

Methodologically, the main contribution of this thesis is the proposed strategy to estimate the effect of intra-seasonal climate variability on household livelihoods. Using the fact that the distribution of temperatures often resembles a normal distribution (Folland, Karl & Salinger, 2002: 155), introducing in the regression model the two parameters that characterize a normal distribution (mean and a proxy for standard deviation, temperature range; and their interaction) and controlling for other key climate related factors that could also affect household decisions

[61] The non-farm income level model shows significant effects for areas with meant temperature below 12˚C.

(mean precipitation and local access to irrigation) we can identify the effect of an increase in temperature variability. Each study optimizes the econometric strategy to estimate the role of climate variability. The main limitation of the first study is that data is aggregated at district level and its main strength is that its panel nature allows to relax the usual assumption of non-correlation between time invariant observables and time variable covariates. To avoid misrepresentation of districts with small cultivated areas in the estimated effect of climate variability, the regressions weigh each district by its cultivated land. This also allows to avoid overrepresentation of districts with less robust climate parameters. The main limitation of the second study is the cross-section nature of the data, but its main strength is the rich information at household and provincial level the EPHR survey provides, that allows to explicitly control for usually unobserved covariates. One of the main challenges of this study is the non-linearity of the economic outcomes under analysis. Given that the goal of the study is to infer household response to changes in climate variability, the normality assumption is important to ensure tests validity. Generalized linear models with family distributions and link functions that fit each outcome were used to circumvent this problem. All models weighed household data by probability sample weights in order to maintain representativity of the rural province territories and adjusted standard errors to account for clustering and heteroscedasticity.

Finally, as usual, measurement errors, especially for income data, are a concern. One of the data quality-checks I performed in early stages of this research process was to compare average income levels for each source of income with those reported by ENAHO 2014 (the living standards survey, also implemented by INEI, that is representative of broad rural Northern, Central and Southern domains only). The decision to aggregate wage and self-employment income sources for farm and non-farm activities was based on the similarities that these aggregates showed between EPHR and ENAHO. Although it is likely that ENAHO under-represents some areas in the rural Andes, given that ENAHO has a stronger questionnaire to capture rural income, I decided to be cautious and aggregate income data into farm and non-farm categories. More detailed information on wage and self-employment income sources in the future will hopefully allow to analyze in further detail the role of climate variability in income diversification strategies.

Associated research topics that may improve limitations of this study.

- The measures of crop portfolio diversification (Herfindahl and intercropping) and relative tolerance to environmental diversity refer to diversification across species, since currently agrarian censuses in Peru do not gather information on crop varieties. Having information on varieties would allow us to better understand adaptation strategies, since we know that Andean farmers do (and have historically) experiment with varieties to achieve more resilient production systems.

- As previously mentioned, the climate parameters used in this thesis were estimated by Ponce, Arnillas and Escobal (2015). The authors explain in that book chapter that it was not possible to estimate standard errors due to methodological limitations, shared by previous studies on small aggregate climate estimates. This implies that the estimated effect of climate variability should be larger, and some of the estimates may lack statistical significance. These estimates could be revised when this methodological limitation is overcome, and standard errors can be estimated. Nevertheless, it is worth to note that the proxy for variability used in this thesis, temperature range, was constructed using the 30-year averages of minimum and maximum temperatures, and is thus closer to a lower bound of temperature variability.

- A gender focus. Since most households headed by a woman are single-headed (90%), future research on gender differences in access to less uncertain income generating strategies should include the potentially lower economic opportunities available to these (female headed) households. Some of the reasons why these households may benefit less from more profitable economic opportunities include the limitations to travel long distances or for extended periods of time (for seasonal migration jobs, direct sale in distant markets, among others). Although these complications are also faced by single-headed households lead by men (34% of single headed households), female household heads face limitations to access resources under the control of traditional local institutions, which tend to favor men. Thus, single-headed households lead by women may fall back on non-farm activities in more precarious conditions.

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EPHR 2014 – Provincial Survey of Rural Households.
CENAGRO 1994, 2012 – National Censuses.