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Ponce, Carmen

Veröffentlichungsversion / Published Version
Forschungsbericht / research report

Empfohlene Zitierung / Suggested Citation:
Ponce, C. (2018). *Adaptation to climate change in the tropical mountains? Effects of intraseasonal climate variability on crop diversification strategies in the Peruvian Andes.* (Avances de Investigación, 36). Lima: GRADE Group for the Analysis of Development. https://nbn-resolving.org/urn:nbn:de:0168-ssoar-94877-7

Avances de Investigación

Desarrollo rural y agricultura

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Carmen Ponce

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GRADE
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Adaptation to climate change in the tropical mountains? Effects of intraseasonal climate variability on crop diversification strategies in the Peruvian Andes

Carmen Ponce[1]

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[1] Associate Researcher at the Group for the Analysis of Development (GRADE).
This paper is part of my doctoral dissertation at the Pontificia Universidad Católica del Peru. I am grateful to my advisors Javier Escobal and Javier Iguíñiz for their helpful comments and encouragement. I also thank seminar participants at the 2016 Conference of the Canadian Economics Asosociation, as well as IDRC officers in Ottawa (June 2016) and seminar participants at the Group for the Analysis of Development (July 2016), for their contributions to an early draft. Remaining errors are, of course, my responsibility.

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Lima, May 2018

GRADE, Group for the Analysis of Development
Av. Almirante Grau 915, Barranco, Lima, Peru
Phone: (51-1) 247-9988
Fax: (51-1) 247-1854
www.grade.org.pe

Research director: Santiago Cueto
Edition assistance: Diana Balcázar Tafur
Cover design: Elena González
Design of layout: Amaurí Valls M.

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ABSTRACT

Crop diversification, selection of tolerant crops, and intercropping are some of the strategies that Andean farmers, as well as farmers in other mountain regions, have historically used to cope with climate-related risks and take advantage of heterogeneous agricultural land (with plots located at different altitudes, facing different environmental conditions). This study analyzes the role of climate variability -during the growing season- in the use of these strategies, in a context of climate change in the Andean region. Using agrarian census data from 1994 and 2012 (district panel), I find that -controlling for other climate conditions and socio-economic factors-, an increase in intraseasonal climate variability leads farmers in colder areas (<11°C during the growing season) to concentrate their crop 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. 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 some specific issues that need to be part of the public intervention agenda.

INTRODUCTION

This study analyzes the effect of changes in intraseasonal climate variability on crop portfolio decisions in the Peruvian Andes[2]. The analysis aims to contribute understanding of the decisions made by small farmers facing changing climate conditions in areas with little or no public intervention (so-called spontaneous adaptation). I focus on three strategies that previous literature suggests are potentially effective for small farmers' adaptation to climate change: diversifying the crop portfolio, shifting the portfolio towards more tolerant crops, and intercropping (companion planting). To the best of my knowledge, this is the first study that uses representative information regarding farmers' decisions over a large region to estimate the effects of intraseasonal climate variability changes on crop portfolio decisions (instead of focusing exclusively on specific major crops). The Peruvian Andes, a mountainous region widely documented as one of the most affected by climate change, is especially interesting as a case study. The region is very heterogeneous in terms of topography and climate, and is mostly populated by small farmers, most of whom have no substantial financial or physical capital, but whose traditional knowledge and experience in crop diversification can become key assets for adaptation to climate change.

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[2] Intraseasonal climate variability is measured here as the 30-year average temperature range, consisting of the difference between the average maximum and the average minimum temperatures registered in a particular trimester during the 30-year period prior to the farmer's decision.

Using an Agrarian Census district panel (years 1994 and 2012), I estimate the effect of intraseasonal climate variability on farmers' crop portfolio decisions, while controlling for other climate conditions (30-year average precipitation and temperature); for socio-economic factors such as local households' assets and demographics (education, household members, and farmers' sex and age), access to technology and mechanization (concrete-lined irrigation canals, tractors, and certified seeds), and farmers' access to technical assistance (either private or public); for institutional factors that affect farmers' access to local resources (unequal distribution of farm land, presence of peasant communities); and for the proportion of farmers who diversify into off-farm income sources. Given the nature of farm activities, heterogeneous conditions such as soil fertility, moisture, topography, and other environmental characteristics, as well as cultural practices and preferences, also tend to play a key role in determining farm production decisions and outcomes. Since this heterogeneity does not change systematically in the short term, the fixed effects estimation strategy helps identify the climate effect.

This paper builds on three previous studies. The first one produced climate estimates appropriate (in terms of scale, year, and periodicity) for analyzing the effects of climate change on agricultural decisions. In order to match district-level information from the 1994 and 2012 Agrarian Censuses, 30-year averages of temperature and precipitation estimates were produced for each trimester starting in August, considered the first month of the agricultural calendar in Peru[3] (Ponce,

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[3] Although the specific sowing and growing months (and the number of seasons) for each crop and region in the country vary, August is considered the beginning of the agricultural calendar. For more information on the agricultural calendar in Peru, see the Ministry of Agriculture and Irrigation website at http://www.minagri.gob.pe/portal/21-sector-agrario/agricola/181-calendario-agricola

Arnillas, and Escobal 2015). The present study uses climate estimates from the second trimester (November-January), when the rainy season is in full force throughout the region and most crops are growing. The second study analyzed the effects of climate and spatially-distant family networks on rural livelihoods in the Andean region. The analysis focused on rural households' decisions to diversify labor income and working hours into non-farm activities (Ponce 2018). The third study aimed to develop a methodological tool to capture differences in crops' tolerance to climate change. Using available census data on the co-occurrence of crops across altitude and temperature gradients, the study adapted the niche-breadth co-occurrence index methodology proposed by Fridley et al. (2007) and evaluated its suitability and robustness to the analysis of the relationship between crop tolerance and intraseasonal climate variability (Ponce and Arnillas 2018). Finally, this current paper estimates the effect of an increase in intraseasonal climate variability on crop portfolio decisions made by Andean small farmers, with the analysis including not only the the crop portfolio's average tolerance to climate conditions (based on the third paper) but the degree of concentration (Herfindahl) and the practice of intercropping as well.

The paper is organized as follows. The first section briefly discusses the literature on crop diversification used as a means to adapt to climate change. This section explains the mechanism through which crop diversification affects crop viability and productivity, and the challenges that farmers face to diversify crops appropriately (information, experimentation, complementary assets). The second section describes the data used in the analysis, as well as the econometric specification to identify the climate effect on crop portfolio decisions. The third section discusses the descriptive and econometric findings, and the final section concludes, raising pending research questions and outlining policy recommendations.

1. 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[4], 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; Porter et al. 2014, Easterling et al. 2007: 294-295; Dell, Jones, and Olken 2014: 757-759[5]).

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[4] The AR4 indicates 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).

[5] Dell, Jones, and Olken (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.

Furthermore, Dasgupta et al. (2014) 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 adaptating to the increasing climate risk (638).

According to AR5, climate-related risks are represented by the "probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur" (Oppenheimer et al. 2014: 1048). Thus, risks involve the interaction of vulnerability, exposure, and hazard. The authors highlight that both vulnerability and exposure to climate risks depend on wealth, social status, and gender, among other factors. Given that most Andean farmers live in poverty and have limited private assets and limited access to public services, information, and markets, it is reasonable to expect them to be highly vulnerable to changing climate conditions. However, as several authors have pointed out, despite these weaknesses, Andean small farmers hold key assets such as traditional agricultural practices, family labor, and community institutions that help them face extreme events and low soil fertility (Mayer 1979; Tapia and Fries 2007).

With regards to vulnerability and small-scale farmers, it is worth highlighting the survey for AR5 completed by Dasgupta et al. (2014), which includes studies by Gbetibouo et al. (2010b) and Bellon et al. (2011). These studies argue that while small-scale farming tends to increase vulnerability, small farmers' resilience based on indigenous knowledge, family labor, and livelihood diversification should not be underestimated (Dasgupta et al. 2014: 634). The study by Brondizio and Moran (2008) also highlights that small farmers tend to be less vulnerable to climate changes affecting a crop's survival, as compared to larger monocrop operations. This lower vulnerability stems from small farmers' practices of crop diversification and on-farm biodiversity. Nonetheless, the authors acknowledge small farmers' limitations in terms of technology and market access (Dasgupta et al. 2014: 634).

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

The literature on Andean farmers and peasant communities has extensively documented crop portfolio diversification as one of the key strategies for minimizing climate risks where there is large climate variability and fragmented agricultural land (Earls 1991, Caballero 1983, Figueroa 1989, Escobal and Ponce 2012). In a thorough early study on the Central Andean Mantaro Valley, Mayer (1979) pointed out the wide intraseasonal temperature ranges in the Peruvian Andes, finding a 17°C mean difference between minimum and maximum daily temperatures during the dry season in Huancayo, the region's most important city (Mayer 1979: 22-23). According to Mayer, Troll (1968) called the Andean climate a "diurnal temperature climate" due to the wide temperature range within a day as opposed to interseasonal variations.

In the last decades, given the heterogeneous climate changes documented throughout the world and associated concerns about food security, several studies from the Biology and Agronomy literatures have identified the mechanisms through which changes in climate conditions affect crop growth or even crop survival. Lin (2011) surveys several such studies investigating the mechanisms. She argues that "climate change will affect biotic (pests and pathogens) and abiotic (solar radiation, water, and temperature) factors in crop systems, threatening crop sustainability and production. More diverse agroecosystems with a broader range of traits and functions will be better able to perform under changing environmental conditions (Matson et al. 1997, Altieri 1999)" (Lin 2011: 184). In this way, Lin emphasizes the importance of building resilience[6] into agricultural systems as a

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[6] Lin (2011: 183) defines resilience as "the propensity of a system to retain its organizational structure and productivity following a perturbation (Holling 1973)."

response to environmental changes, which include—but are not limited to—climate change. Furthermore, Lin warns about the limited attention that the scientific community has afforded to building resilience into agricultural systems, as compared to the attention given to other ecosystems also affected by external changes, such as coral reefs or forests (citing studies by Nystrom et al. 2000 and Chapin 2004).

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 (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. The present study focuses on spatial diversification of crops, which can be implemented at different scales, such as: (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). Here I will focus on (ii) and (iii), as well as on the selection of crops relatively more tolerant to diverse environmental conditions.

As previously mentioned, crop diversification enhances an agricultural system's ability to deal with pests and diseases that affect crop growth. Poveda, Gómez, and Martinez (2008) discuss the theoretical mechanisms, explaining how vegetation diversity affects crop pests. According to the authors, there are three main mechanisms: disrupting the pest's ability to locate the host plant, increasing the pest's mortality, or repelling the pest (Poveda, Gómez, and Martinez 2008: 132). By reviewing 62 studies, some of which include intercropping practices, the authors 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 authors emphasize the need to choose the "right kind" of diversity. In particular, the authors mention the study by Heemsbergen et al. (2004) that suggests that functional differences between species, instead of the mere number of species, enhance overall ecological function. Based on that study, Poveda, Gómez, and Martinez argue that each species' contribution to the functional groups in a community may explain the link between biodiversity and ecological services like pest control (Poveda, Gómez, and Martinez 2008: 134). Thus, identifying the right combination is key to achieving the goals of pest control and yield enhancement, a caveat needed for explaining the difficulties that Andean farmers may face when attempting to adapt current intercropping practices to new climate conditions, in the absence of information and technical assistance for choosing the right crop combinations.

Empirical studies focused on the Andean region support the conclusions drawn by Lin and Poveda, Gómez, and Martínez 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. 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 (Gianoli et al. 2006: 284). They also discuss previous studies conducted in other regions of the world (Altieri and Whitcomb 1980, Altieri 1994, and Altieri and Letourneau 1999), which show a lower density of insect pests when maize is grown in diversified cropping systems (Gianoli et al. 2006: 284). In addition, Poveda, Gómez, and Martinez (2008) argue that previous studies show the effectiveness of intercropping for controlling pests and increasing yield (they mention Pitan and Olatunde 2006 for cowpea, okra, and tomato; and Vandermeer 1989 and Altieri and Nicholls 1994).

As previously mentioned, there is a vast literature about the impact of climate change on the individual crop yield of major crops (maize, wheat, sorghum). 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 and Wheeler 2009: 2530). The authors mention 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 3 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 relative tolerance to climatic changes, Ponce and Arnillas (2018) propose an index based on the concept of the ecological niche of a species (a crop in this case), which 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 it exhibits more tolerance to environmental changes. In the following sections, we estimate and analyze a proxy indicator of a crop's relative degree of tolerance, to complement the analysis of the effects of intraseason climate variability on crop diversification and intercropping practices.

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

As the literature on agricultural production strategies shows, the degree of diversification of a crop portfolio 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).

Regarding farmers' perceptions, several qualitative studies—especially in African and Latin American countries—document that rural households perceive changes in climate conditions (Thomas et al. 2007; Escobal and Ponce 2010; Vergara 2012; Postigo 2012; among others). Postigo (2012) conducts a study of high-altitude Andean pastoralists, regarding their perceptions and responses to climate change. Postigo 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 due to severe changes. It is worth noting that several researchers have warned about other global changes that need to be considered along with climate change in order to more effectively address the challenges that farmers face currently and in the future (Glave and Vergara 2017; Postigo and Younge 2016).

While many qualitative case studies have been conducted about farm households' perceptions 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. One of these few was conducted by Kurukulasuriya and Mendelsohn (2008), who combine the agro-economic and Ricardian model frameworks to identify the impact of climate change on farmers' crop-related decisions. Based on data from 5000 farmers across 11 African countries, the authors find that climate does affect farmers' crop choice and thus point out the limitations (potential overestimation) of climate change impact models that assume no adaptations of crop portfolios by small farmers.

Another exception is the study by Deressa, Hassan, and Ringler (2011) on Ethiopian farmers. They model adaptation as a two-step process, with a first period where 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, and are found to depend on the 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.

From a different approach, Fankhauser (2016) surveys the literature on adaptation to climate change and notes that most studies on private (autonomous) adaptation are focused on agriculture. The author highlights that short-term responses to weather variability include diversifying into non-farm activities, reducing the farm size, and when available, using weather insurance. Additionally, Fankhauser (2016) highlights a study by DiFalco and Veronesi (2013) for Ethiopia that shows that the effectiveness of adaptation 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 challenges for small farmers in poverty—like the majority of Andean farmers in rural Peru.

For a broader perspective about the effects of climate on economic outcomes, it is worth mentioning the methodological progress of the so-called Climate Economics literature in the last two decades. Hsiang (2016) classifies the studies on the effects of climate on economic outcomes (including agricultural outcomes) into three groups, according to their methodological approaches. Sections 2 and 3 of this article benefited from Hsiang's review. According to Hsiang (2016), early studies were based on cross-sectional estimates, which depend on the plausibility of the homogeneity assumption (i.e., if two regions experience the same climate, both regions should have the same expected conditional outcomes). The weakness of cross sectional estimates, thus, lies in a likely but not measurable bias derived from omitted variables (Hsiang 2016: 5). As time-series weather data was made available, a second group of studies managed to overcome the omitted variables bias by taking advantage of repeated observations for a specific region or farmer. Hsiang highlights, however, that this approach assumes that "the effect of a marginal change in the distribution of weather is the same as the effect of an analogous marginal change in the climate" (2016: 6). As I discuss in the following section, this is a particularly challenging assumption for crop portfolio decisions (as compared to revenues or outcomes). This is so because, as Hsiang explains, climate affects economic outcomes in two ways: directly (climate influences weather occurrences—for example, the occurrence of an extreme event like hail that causes crop loss), and indirectly (climate affects farmers' beliefs, which in turn affect their decisions about which crop to grow or how to do so—for example, using irrigation systems to affront expected droughts). Whereas time-series estimators based on short-term weather events may capture direct effects, short-lived extreme events may not affect farmers' beliefs. Since the present study focuses on crop portfolio decisions instead of final outcomes (yields or revenues), the role of indirect climate effects on farmers' beliefs is key to the methodological estimations. Dell, Jones, and Olken (2014) also surveyed studies about the relationship between weather (short-term climate events, based on daily or yearly data) and agriculture, among other economic activities and outcomes. These authors acknowledge that studies on weather and economic outcomes cannot automatically be extrapolated to climate economics discussions, but they can inform our understanding of the impacts of climate change to some extent. Notably, the authors review studies that use longer-term climate and outcomes data. One of them, their own study from 2012, used 15-year average climate data to study the effects of climate conditions on economic growth in several countries (1970-1985 and 1985-2000). They found negative effects, with intensification effects outweighing adaptation for poor countries (Dell, Jones, and Olken 2014: 778). They also mention the shorter-term study by Burke and Emerick (2013) in the United States, which contrasted climate data from two distant 20-year periods, 1978-1982 and 1998-2002, and found evidence of adaptation to warmer temperatures.

A third methodological approach discussed by Hsiang (2016), the long-difference estimator, aims to overcome the previous two challenges, the omitted variables bias of cross-section estimates and the marginal treatment comparability assumption of time-series weather estimates. Despite the strength of the long-difference estimator, Hsiang identifies a potential weakness: although the long-difference approach relaxes the strong homogeneity assumption required for an unbiased cross-sectional estimator, a weaker version of this assumption is still required for the long-difference estimator (outcome changes across regions are assumed to be comparable).

Based on previous research, what would be the expected effect of an increase in intraseasonal climate variability on crop-related decisions?

As previously mentioned, this paper focuses on farmers' three crop-related decisions: the degree of diversification of the crop portfolio, the portfolio's relative tolerance to climate variability, and the percentage of farm land allocated to intercropping practices. An increase in climatic variability may lead to greater variability of yields (Porter and Semenov 2005) and potentially yield loss if lower temperature thresholds for the crop are reached. Thus, I expect that an increase in climate variability during the growing season will lead farmers in cold areas to diversify their crop portfolio to minimize risk, as well as to allocate more land to crops with a greater tolerance to broad temperature variability. I do not expect these effects to be significant in areas with mild climate conditions, mainly because in such areas there is no actual risk of close to freezing temperatures induced by a broader temperature range.

In contrast, I do not have a clear hypothesis regarding the effect of intraseasonal climate variability on farmers' decisions about intercropping practices. As described above, previous research shows that adequately implemented intercropping is an efficient response to the pests and diseases that affect crops when temperature and moisture increase. However, I found no research on the effectiveness of intercropping when temperature variability during the growing season increases (controlling for changes in average temperature and precipitation). Given that the effectiveness of intercropping practices requires specialized knowledge and inputs, the new companion crops that effectively adapt to changing climate conditions may not be easily known or accessible for Andean farmers. If this is the case, farmers may choose an alternative adaptation response (such as increasing crop diversification or selecting more tolerant crops), and estimates would show a decrease in intercropping practices as temperature range increases. This, however, remains an empirical matter discussed in Section 3.

2. DATA AND METHODS

2.1. 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 only at the district[7], province, and department levels. Therefore, to obtain spatially comparable information for both years, I aggregated household information at the district 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[8]. Two thirds of these districts have most of their territory in the Andean region and thus were included in the estimation that follows.

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),

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[7] Districts are the smallest units of political-administrative demarcation in Peru.

[8] Only districts with crop farming activity in both census years were included in the analysis.

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.

Three crop-related decisions are studied: degree of crop diversification, the crop portfolio's relative tolerance to climate diversity, and the percentage of farm land allocated to intercropping practices.

a. The Herfindahl indicator, used in the following section, measures the degree of market concentration and is widely used in the Economics literature. It has also been used in the Agricultural Economics literature to represent the degree of concentration of the 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 average index for a district is calculated as the average H_j weighted by farm j land size.

b. A crop's relative tolerance to climate variability was estimated following the methodology proposed by Ponce and Arnillas (2018). The multisite crop index is a co-occurrence index capturing the degree of tolerance of crops to diverse environmental conditions. The multisite district index used in Section 3 is a weighted average of the multisite crop index weighted by the district land where each crop is cultivated.

c. Finally, with regards to the third indicator, the land share allocated to intercropping is the average land allocated by a district's farmers weighted by the size of their farm land. According to INEI (2014), the crops registered 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).

Climate (estimates)[9]

The data on climate conditions used in this study was the average conditions estimated 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 the average temperature and precipitation at the district and province levels between 1982 and 2012, closely following 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 Comission for Latin America and the Caribbean.

This methodology consists of implementing co-kriging to interpolate temperature, using altitude as a covariate due to the strong physical link between the two variables (temperature decreases at higher altitudes because of the lower air pressure). For the interpolation of precipitation, Ponce, Arnillas, and Escobal (2015) used complementary information

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[9] The following three paragraphs summarize the explanation of climate data reported by Ponce (2018).

recently acquired by the Tropical Rainfall Measuring Mission to create maps of the probability of precipitation by trimester. Although this information is not available for the entire period under analysis, it allows for establishment of the spatial structure of precipitation level and changes throughout the year. Given that such spatial structure depends greatly on topography and wind direction and there was no evidence that either one of these had changed in the last 50 years, the authors argued that it was sensible to assume that the spatial structure of precipitation had not changed for the period under analysis (2015: 218).

The climate estimates used in this study are aggregated at the district level but only include areas below 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.

It is important to emphasize that the temperature range estimate, used here as a proxy for intraseasonal climate variability, is the difference between the trimester's 30-year average maximum temperature and its 30-year average minimum temperature as originally estimated by Ponce, Arnillas, and Escobal (2015). The 30-year average minimum temperature estimate was based on spatial interpolation of the 30-year average of daily minimum temperatures reported by the meteorological stations, and analogously done for the 30-year average maximum temperature. Therefore, the temperature range estimate does not aim to capture the most extreme minimum or maximum temperature anomalies registered during those 30 years (weather shocks). Instead, it aims to capture long-term intraseasonal climate variability and thus, I argue, to approximate small farmers' expectations about intraseasonal climate variability during regular years like 1993-4 and 2011-2 (years when Peru did not face a strong El Niño or La Niña event)[10].

2.2. Model and empirical specification

The conceptual framework that underlies this analysis follows the model discussed by Ponce (2018: 10-13). In that model, rural households decide on income diversification strategies based on the resources that they control and their expectations about factors that they do not control (but can affect their economic outcomes), such as climate conditions and market prices. Comprising three time periods, the final observed economic outcomes (income, working hours) depend on (i) the household's initial decisions, (ii) further adjustments of such decisions after experiencing the climate conditions during the growing season (remedial actions), and (iii) final market equilibrium prices and transactions. Therefore, the household's expectations for the growing season's climate conditions are key for crop portfolio decisions in the first period, whereas the actual climate conditions during that season are key for the following two periods. For instance, if an extreme event occurs and the crop yield is lost, the model predicts that the household will take some remedial action in the second period (by increasing off-farm work if possible, for example[11]). In the third period, crops' market prices would be higher than expected (due to a crop supply shortage), and the household's agricultural income would

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[10] As discussed in this paper, if small farmers expect a strong El Niño or La Niña that may severely affect their crops, they may make extraordinary decisions with regards to work and resources allocated to farm and off-farm income generating activities.

[11] Given that decisions about the type and amount of work and assets to be invested in each activity are made in the first period, adjustments in the second period are limited.

be lower than expected; but the total household income may not be as affected due to the remedial action taken in the second period. Thus, a combination of both, the ex-ante climate expectations and the ex-post climate realization, determines farmers' economic outcomes.

In the present study, I focus on the decisions made by the farmer only in the first period of the model. In this period, households decide which type of income-generating activities they will perform and the corresponding working hours and assets they will invest in each one. In particular, I focus on farm-related decisions that result in a certain degree of concentration of the crop portfolio (Herfindahl index), the relative importance of more tolerant crops (Multisite index), and the land size allocated to intercropping practices.

As discussed in the first section, farmers' decisions about crop portfolios depend on a variety of factors (social, cultural, economic, and even institutional) besides environmental biophysical conditions. In an economic activity as vulnerable to risk and uncertainty as agriculture, unobservable individual characteristics such as risk aversion and entrepreneurship can play a key role. Fixed effects estimation allows us to control for these key characteristics that hardly change in the short term. Farmers' decisions, of course, will be 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 markets and technologies. At the same time, their experience is influenced by past biophysical environmental conditions, as well as structural market changes. 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 access to and use of key agricultural assets such as land and water in important sectors of the sub-region. Social capital can 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).

Econometric specification

The effect of intraseasonal climate variability on each of the three indicators associated with crop portfolio decisions (Herfindahl index, Multisite index, and land allocated to intercropping), D_{it}, is estimated by taking advantage of the panel structure of the data, using the following reduced form:

$$D_{it} = \alpha + x_{it}\beta_1 + z_i \beta_2 + \mu_{it}$$
$$\mu_{it} = v_i + \varepsilon_{it} \text{ , } \varepsilon_{it} \sim \text{i.i.d.}$$
$$t = 1994 \text{ ,}2012$$

While x_{it} represents the set of time-variant variables influencing the farmer's decision about his or her crop portfolio at time t, z_i represents the corresponding time-invariant characteristics that also affect the decision. 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, this estimation strategy has the advantage of relaxing the usually required assumption of zero correlation between v_i (and all other time-invariant characteristics z_i) and the time-invariant variables x_{it}. Thus, for example, we do not need to assume 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. A district's climate estimates for the growing trimester, based on the interpolation of meteorological stations' daily data, are used here as proxies for farmers' expectations regarding climate conditions during the growing season. Since individual expectations of climate may differ due to differences in farmers' experiences and abilities to access and interpret climate information, I further control for these individual characteristics in the estimation (age and education of the household head).[12]

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 intrapanel 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 intraseasonal climate variability on farmers' crop portfolio decisions also differs across areas, even when controlling for average 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.

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[12] As explained in the previous sub-section, climate estimates as well as farm households' information are available and analyzed at the district level.

3. RESULTS AND DISCUSSION

As mentioned before, the Andean region is quite heterogeneous in terms of farmers' socio-economic characteristics and cropping strategies, as well as 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 present descriptive results of 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 effect of intraseasonal climate variability (measured by intraseasonal temperature range) during the growing trimester on crop portfolio decisions, controlling for both time-variant and time-invariant confounding factors.

3.1. Descriptive results

Climate conditions in the Andean region

The strong impact of global warming on accelerating glacier retreat has caused decreased 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). Even in areas with no major influence of glaciers, the hydric regime can still be quite heterogeneous.

In the Andean region, water availability, key to agricultural productivity, depends on precipitation and access to irrigation systems. 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. In general, the Northern subregion benefits from heavier rain than the Central and Southern subregions, but it is possible to find very dry and very wet areas within each sub-region[13].

On average[14], temperatures in the Northern Andes are warmer and less variable than in the Central and Southern Andes. The dry season is the coldest, with 30-year average minimum and maximum 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 average 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. The 30-year average minimum temperatures during the November-January trimester, however, are closer to 0°C, ranging from 4 to 15°C in the North, 0 to 11°C in the Central part, and -2 to 13°C in the Southern

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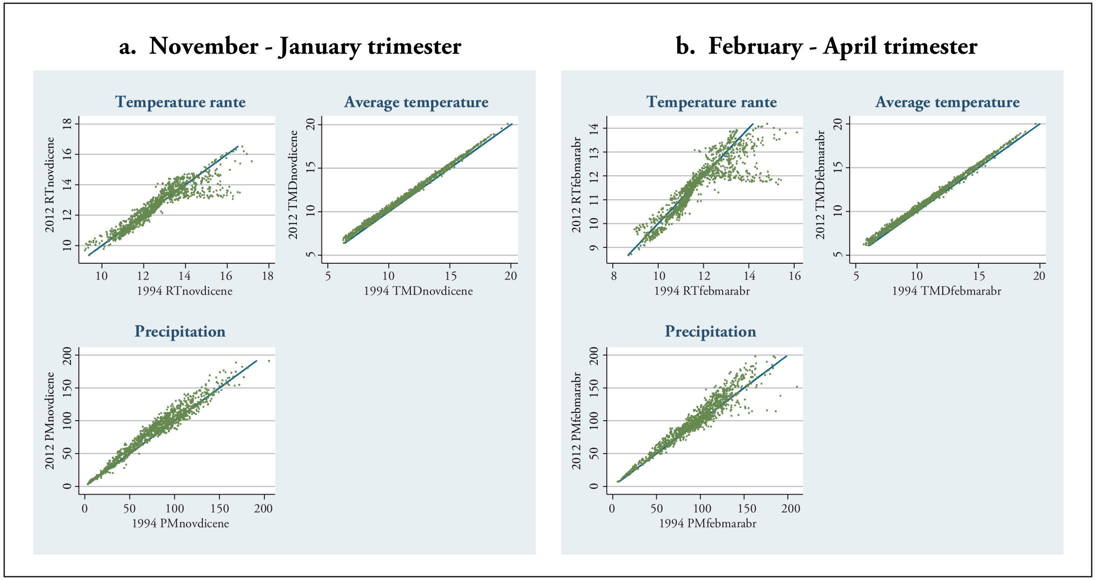
[13] As mentioned before, in agriculture the timing of rain can be as important as the amount (Vergara 2012). However, there is no information available to discuss changes in timing at the spatial and time scales so as to be representatively compatible with this study. Vergara (2012) conducted a qualitative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

[14] As previously mentioned, average estimates of climate conditions in the Andean region —and for the Northern, Central, and Southern sub-regions— exclude areas above 4800 m.a.s.l. and are weighted by each district's cultivated land, to represent climate conditions faced by farmers in the region.

Graph 1

Change in temperature range, average temperature, and precipitation during the rainy seasons in 1994 and 2012 (November-January and February-April trimesters), 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) sub-region. It is worth emphasizing that these minimum temperatures represent 30-year averages of minimum temperatures, and thus are more representative than the individual weather shocks from the extreme climate that Andean farmers usually face during the growing season. Given the high sensitivity of crops to close-to freezing temperatures, analyzing the effect of changes in temperature range on crop portfolio decisions is key to agricultural sustainability in the Andean region.

Like measurements, changes in climate conditions are also heterogeneous in the Andean region. While average temperature shows a systematic increasing pattern during the rainy season (on average 0.4°C higher in 2012 as compared to 1994), temperature range and precipitation show heterogeneous trends. As Graph 1 shows, changes in temperature range and precipitation vary across the Andes. This is true in both trimesters of the rainy season.

Given that larger changes are found in areas with wider temperature ranges, typically located in the Central and Southern Andes, I consider sub-regional patterns during the rainy season[15]. To account for the relative importance of districts in terms of agricultural activity in the Andean region, Graph 2 shows the relationship between both year's estimates, weighting district estimates by their cultivated area. While the Northern sub-region shows a strictly increasing relationship (i.e., no difference in patterns of change between areas with high versus low variability), the Central sub-region shows a strictly increasing trend only in areas with a smaller temperature range. For areas with higher variability, the relationship is not strictly increasing, and it even begins to decrease at the end in Central districts. The South shows similar patterns to the Central sub-region, only weaker.

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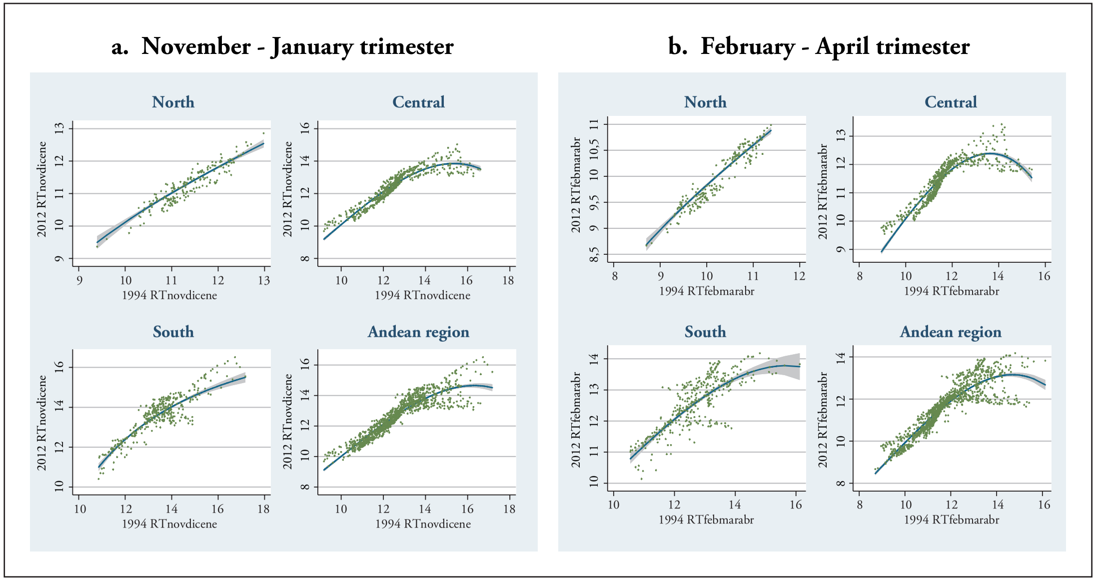
15 During the rainy season, the heterogeneity of changes in temperature range is the highest. Graph A5 in the Annex shows the changing patterns for the dry season (May-July and August-October trimesters).

Graph 2

Patterns of change in intraseasonal temperature range during the rainy months (November-January and February-April), by sub-region



a. November - January trimester

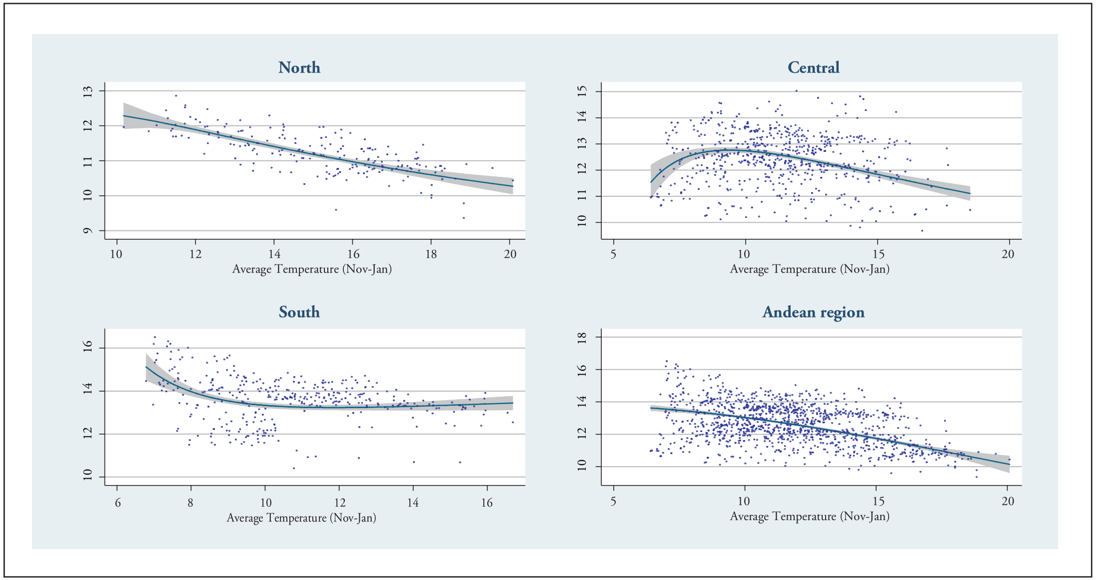
b. February - April trimester

Note: The curve is a fractional polynomial fit, weighted by the district's cultivated area. The dots represent the district's observations.

Source: Based on district climate indicators estimated by Ponce, Arnillas, and Escobal (2015)

Graph 3

Average temperature and temperature range in the Andean region for the November-January trimester, 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, Arnillas, and Escobal (2015)

Since temperature range plays a key role in crop survival at low temperatures, it is important to assess whether long-term average temperature is systematically correlated with temperature range in the Andean region. Graph 3 shows a negative correlation between average temperature and variability in the North, but no systematic relationship is found in the South or Central Andes. To control for such diverse relationships, the econometric estimates discussed below include the interaction between average temperature and temperature range.

Farm households in the Andean region

Along with the 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 increasing in importance, accounting for 0% of household labor income in the poorest decile, and up to 51% in the richest decile (Ponce (2018) estimates based on 2014 survey data). 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). Household demographics have also changed. Andean farm household heads are, on average, more educated and slightly older than they 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 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 not completed primary school 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 1 shows, the Central and Southern farm household profiles were similar in 2012, but Northern 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 find the highest increase in household head's average education level (27% increase in household heads with primary education or higher) and the largest reduction in number of household members (2). The

Table 1
Characteristics of agricultural households living in the Andean region (2012), by sub-region

	Andean region	Northern Andes	Central Andes	Southern Andes
Household characteristics				
% household heads with primary school education or higher	31%	19%	33%	31%
Average number of household members	3.3	3.3	3.4	3.3
% households headed by a man	65%	65%	65%	65%
Average age of the head of household	50	48	51	50

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 Multisite index.

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 primary education or more fall by 13%). Southern households show more educated household heads (household heads with primary education or more 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).

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 land with monocrops. Crop portfolios are more concentrated in the Northern area than in the Southern and Central areas.

With regards to farmers' production technology, the most noticeable changes between 1994 and 2012 are increasing interest in technified—as opposed to gravity—irrigation systems (although gravity systems are still the norm), and increasing mechanization with use of 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 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

Table 2

Farm households' decisions about technology and economic activities (2012), by sub-region

	Andean region	Northern Andes	Central Andes	Southern Andes
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 farms managed by a *comunero* (member of a peasant community)	16%	4%	15%	26%
% 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 Multisite index.

improves agricultural productivity, was already low in 1994 (12%) and fell considerably to 6%. The censuses also show less access to technical assistance throught 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.

The correlation between the three strategies is statistically significant for most pairwise comparisons within sub-regions (Table 3)[16]. First, census data in Table 3 suggests at least partial substitutability between the strategies of intercropping[17] and of choosing a more concentrated, more tolerant crop portfolio. The second finding derived from Table 3 is that the degree of land concentration devoted to particular crops (Herfindahl index) is positively correlated with the average degree of tolerance to environmental diversity (Multisite index), though this finding is less robust. This suggests several adaptive scenarios, like (i) farmers allocate a larger land share to more tolerant crops that were already in their portfolio, but keep the same set of crops, or (ii) farmers introduce new, more tolerant crops into the portfolio and assign them larger land shares than those allocated to previous crops

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[16] The correlations decrease in magnitude, but the correlation signs remain the same when using 1994 average values.

[17] According to INEI (2014), the main annual crops cultivated with intercropping in Peru are Maize-Beans (Maíz-Frijol), Fava Bean-Maize (Haba-Maíz), and Oca-Olluco. The main perennial companion crops occupying over 10 thousand hectares per pair are Coffee-Plantain, Coffee-Yuca, Clover-Rye Grass, Cacao-Plantain, and Cacao-Coffee (INEI 2014: 144-146). In the country, 5.6% of cultivated land is allocated to intercropping or companion cropping. The Amazon rainforest region has the largest proportion of intercropping, on 7.8% of its cultivated land, while the Andean region and the Coast have smaller proportions, on 4.4% and 3.6%, respectively (INEI 2014).

(possibly substituting for some crops that used to be in the portfolio), among other scenarios. The only exception is the Central sub-region, which shows a negative correlation between Herfindahl and Multisite indices, suggesting one of the following scenarios, among others: (i) farmers diversify their cultivated land by introducing new crops instead of partially replacing old ones (this scenario is consistent with cautious experimentation with adaptive measures, in that households try new crops but keep some land with the traditional ones as well), or (ii) farmers concentrate their crop portfolio with crops that seem to be less tolerant to environmental diversity but are highly valued in certain markets, and thus are cost-efficient even though their production requires higher costs for technology or inputs. Although market dynamics and accessibility are greater in large sectors of the Central sub-region, the latter scenario seems less likely than the former one for most farm households.

Table 3
Pairwise correlation between changes in crop portfolio strategies from 1994-2012, by region

Change from 1994-2012	Andean region		Northern Andes		Central Andes		Southern Andes	
Herfindahl index - Multisite Index	0.04		0.22	***	-0.09	**	0.14	***
Herfindahl index - Intercropping area (ln)	-0.14	***	-0.03		-0.18	**	-0.14	**
Herfindahl index - Intercropping land share	0.13	***	0.31	***	0.09	**	0.12	**
Multisite index - Intercropping area (ln)	-0.14	***	-0.29	***	-0.02		-0.24	***
Multisite index - Intercropping land share	-0.09	***	-0.11	@	-0.11	**	-0.11	**
Intercropping area (ln) - Intercropping land share	0.5	***	-0.66	***	0.49	***	0.58	***

Note: District observations were weighted by cultivated area.

*** p<0.01, ** p<0.05, * p<0.1, @ p<.15

These correlation patterns suggest that the hypothesis of an increase in crop portfolio diversification as a strategy to adapt to changing climate conditions may be plausible in the Central Andes, but other strategies (increasing the number of tolerant crops in the crop portfolio) seem to be more relevant in the Northern and Southern sub-regions. The next section controls for confounding factors that may explain these correlations, and thus assesses whether the hypotheses we discuss here are plausible.

3.2. Estimation results

The econometric specification

This sub-section presents the estimation results. As mentioned in Section 2, the effect of an increase in intraseasonal climate variability on crop portfolio decisions is estimated as a fixed effects model that controls for key time-invariant district characteristics and time-variant factors that may affect farmers' decisions. As previously discussed, these factors and their evolution over time are quite heterogeneous across the region.

Regarding climate-associated factors, the estimations control for temperature conditions (average and variability) and precipitation. Following Dell, Jones, and Olken (2014), identifying intraseasonal climate variability effects with econometric methods requires including climate conditions that may correlate with the indicator under analysis; otherwise, the correlation between the error term and intraseasonal climate variability would induce bias. On the other hand, given the high correlation of climate conditions across trimesters, I focus on climate indicators associated only with the first trimester of the rainy season (November-January). As discussed in Section 1, this is the most important season when analyzing the effect of intraseasonal climate variability, since crops are most vulnerable to extreme temperatures during the flowering phase (Minagri-Senamhi 2011; Craufurd and Wheeler 2009). In fact, the role of precipitation in crop portfolio decisions is likely to be affected by farmers' access to irrigation systems, although precipitation is not the main variable of interest in this study. Given the partial substitutability between precipitation and irrigation systems, farmers in areas with low precipitation but easy access to irrigation systems could show behavior similar to farmers in areas with moderate, timely precipitation and more difficult access to irrigation. Therefore, the estimations control for the percentage of farmers that have access to irrigation systems in at least one of their plots (whether gravity, aspersion, dripping, or another system).

These indicators of climate and irrigation availability control for temperature conditions (average and variability) and access to water. As previously mentioned, I hypothesize that, ceteris paribus, intraseasonal climate variability has a significant effect on crop portfolio decisions in colder areas, but not necessarily in warmer ones. To test this hypothesis, I include the interaction between intraseasonal climate variability and average temperature.

Household characteristics are also included in the estimations. These characteristics account for differences in skills, experience, family labor force, and vulnerability, by controlling for the household head's formal education, age, and sex, and number of household members. It is worth mentioning that female-headed households are usually more vulnerable to shocks, as they have more limited access to community-regulated land, are usually single-headed, and tend to have a higher dependency ratio.

Some covariates are aggregated at the provincial level to avoid endogeneity issues. This is the case of technology-related indicators, such as the percentage of farms using certified seeds, tractors (mechanized agriculture), and concrete-lined canals for irrigation, as well as the percentage of farms that receive technical assistance. These province-level covariates convey information about opportunities for accessing such technologies or assistance.

As previously mentioned, rural households are increasingly involved in non-farm activities (Reardon et al. 2007; Escobal 2001; Ponce 2018), and their relative involvement in such activities may reduce incentives to invest time and resources in adapting farm practices to changing climate conditions. To control for socio-economic conditions that may make such strategies more attractive than investing in farm adaptation strategies, I control for the percentage of farmers in the province that diversify income-generating sources into non-farm activities. This indicator aims to capture differences (between areas and years) in non-farm job opportunities available to local farmers in local markets.

Local institutions in some areas of the Andean region play an important role in access to and control of key resources, such as land and water. To control for differences in institutional features, the estimations control for the percentage of farms that are managed by a member of a peasant community and inequality in the distribution of cultivated land, as measured by the land Gini of quality-equivalent hectares. Finally, I include a year dummy to control for other characteristics that may have changed between 1994 and 2012 at the regional level. The detailed results of each estimation can be found in Annex A3.1-3.

Discussion

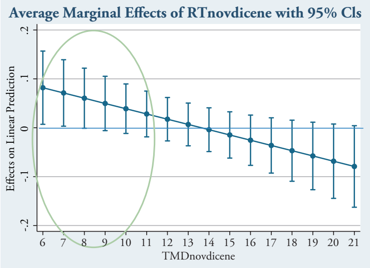
The first key finding of this study is that an increase in intraseasonal climate variability (temperature range) affects colder and warmer areas in the Andes differently. As Graph 4 shows, in colder areas, an increase in intraseasonal climate variability would lead farmers to increase the tolerant crops in their crop portfolio and further reduce cultivated land allocated 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 a particular crop) or implementing intercropping practices (which, if properly implemented, can help control pests and diseases as well as improve soil fertility).

Though both the Herfindahl and the Multisite indices capture changes only at the crop species level, we know from previous studies that changing to varieties of the same species is another potentially effective adaptation practice in the face of changes in intraseasonal climate variability (Lin 2011). Due to the limitations of the census panel data, which provides information on species but not on varieties, these estimates can be interpreted as the lower bound of the effect of intraseasonal climate variability on the degree of diversification and on the average tolerance of a crop portfolio. More detailed information is needed to refine the Multisite index at the level of individual crops, and to estimate the Herfindahl index and average Multisite index at the district level more precisely.

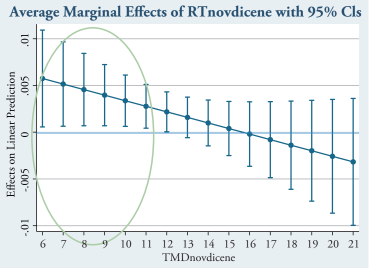
Looking into average marginal effects (in contrast with Graph 4, which shows the marginal effects along the temperature gradient), I find that intraseasonal climate variability has a positive but non-significant

Graph 4
Marginal effect of temperature range on crop portfolio decisions, Andean region

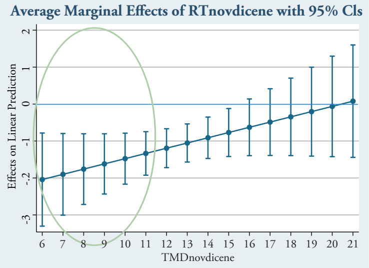
a. Herfindahl Index (concentration of land by crop)



b. Multisite index (district average of crops' relative degree of tolerance to a broad range of climate and soil characteristics)



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



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.

effect on crop portfolio concentration (Herfindahl). In turn, the significant effects on intercropping and on the average degree of tolerance to environmental diversity found in colder areas remain when looking at average marginal effects (see Annex A4, underlined figures).

Regarding the relevance of the loosely termed colder and warmer areas in terms of population, 43% and 68% of farmers in the Central and Southern sub-regions, respectively, live in districts with average temperatures of 11°C or below during the growing trimester. In turn, only 1% of Northern farmers live in districts with such a low average temperature. Therefore, the previous discussion seems to be relevant only for the Central and Southern sub-regions. This also raises the question as to whether the estimated effects are biased by unobservable sub-region characteristics. I look into this potential source of bias in the following sub-section.

Looking into sub-regions

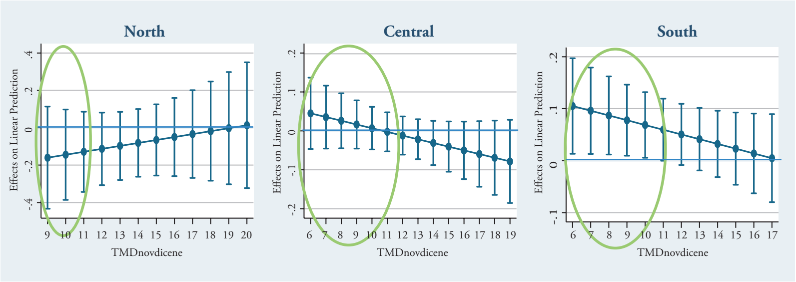
Given that the Northern, Central, and Southern sub-regions differ in terms of climate conditions (temperature and precipitation) as well as socio-economic and institutional features (market dynamism, the role of external actors, the relative importance of peasant communities as local institutions that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

The results obtained by separately estimating the effect of intraseasonal climate variability for each sub-region confirm that the previous estimates (for the overall Andean region) hide important heterogeneities that help understand households' responses to climate change. In the Central sub-region, where low temperatures are common, the

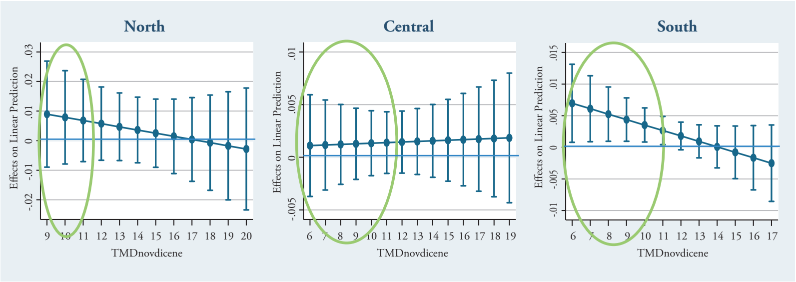
Graph 5

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

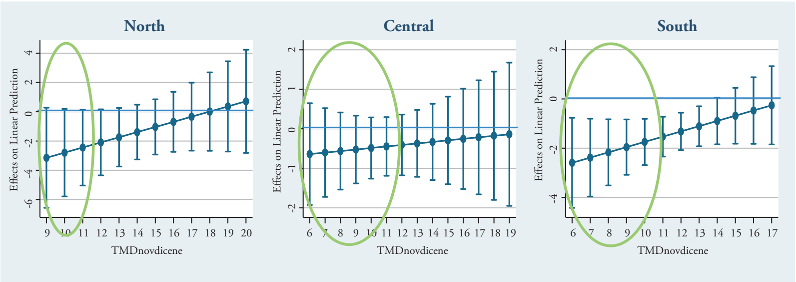
a. Herfindahl Index (concentration of land by crop)



b. Multisite index (district average of crops' relative degree of tolerance to a broad range of climate and soil characteristics)



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



intraseasonal climate variability effect is no longer significant when allowing for full sub-region parameter heterogeneity (i.e., sub-region-specific parameters for all covariates in the regression). This lack of climate variability effect could be explained by a previous study's findings on the effects of intraseasonal climate variability on non-farm income diversification (Ponce 2018: 31-32). That study found that rural households in the Central sub-region respond to an increase in intraseasonal 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 intraseasonal 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.

According to the estimates, Southern farmers respond to an increase in intraseasonal climate variability by concentrating their crop portfolio with more tolerant crops, and decreasing the land allocated to intercropping (Graph 5, Annex A3). This is consistent with a previous study's findings about the effect of climate variability on labor income sources, which 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 (Ponce 2018).

Contrasting the result with the original hypothesis

Consistent with the hypothesis mentioned in Section 1, farmers in cold areas of the Southern sub-region do shift their portfolios towards more tolerant crops when facing higher climate variability (Graphs 4-Andes and 5-South; Andes and Southern regressions in Annex A4). I do not find significant results for the North or Central sub-regions, however.

The results reject the hypothesis that a higher degree of crop diversification would be a response to greater climate variability. As mentioned at the beginning of this paper, I expected higher diversification as a means of diversifying the risk from greater climate variability, but I found no significant effect in the North or Central sub-regions. Only the Southern farmers show a significant response to an increase in climate variability, and it is opposite what I originally expected: they concentrate their crop portfolio more. Putting the two results together, Southern households respond to greater climate variability by concentrating their crop porfolios towards more tolerant crops. These results for Southern farmers are consistent with a previous study (Ponce 2018) that found that households in this sub-region increase working hours allocated to agricultural activities (with no decrease in non-farm income share) when facing an increase in climate variability.

Finally, I find significant effects of climate variability on intercropping practices in the cold areas of the Northern and Southern sub-regions. Consistent with the hypothesis, I find that an increase in precipitation induces farmers to allocate more land to intercropping practices in the Northern and Central sub-regions. As previously mentioned, intercropping practices (when appropriately implemented) are effective for controlling pests and disease outbreaks and preserving or increasing the crop yield.

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 intraseasonal climate variability on crop diversification strategies, it is necessary to control for other confounding factors that could influence households' decisions. The Haussman 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 the observed time-variant covariates and the unobserved time-invariant factors (see Annex A4.1-A4.3). 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 Tables 1 and 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.

4. CONCLUSIONS AND POLICY DISCUSSION

Like other mountainous regions, the Andes shows different altitudinal ecosystems and heterogeneous intraseasonal climate variability, and Peruvian farmers have historically relied on traditional agricultural practices, including crop diversification (cultivating different crops and different varieties of the same crop and implementing intercropping practices, among other forms of diversification), to cope with and take advantage of these features. Although such local experience and knowledge may be useful for developing spontaneous adaptation strategies, previous studies have found that Andean farmers are struggling with climate unpredictability and increasingly frequent extreme climate events. Given the widespread poverty prevalent in the region, they still lack assets and information for optimal adaptation to the changing climate conditions.

This study aims to contributing to our understanding of how small farmers living in areas with little or no public intervention adapt to climate change. The study focuses on three strategies identified by the literature as potentially effective adaptation measures: (i) diversifying crops across their farm land, (ii) shifting their crop portfolio towards more tolerant crops, and (iii) using intercropping practices (which, when used appropriately, are found to effectively control pests and disease).

Previous climate estimates by Ponce, Arnillas, and Escobal (2015) show an increase in average temperatures in the Andean regions below

4800 m.a.s.l., especially during the rainy trimesters. Precipitation estimates are heterogeneous, increasing in the North during the rainy season and decreasing in some areas of the North and South sub-regions during the crop growing trimester. Using the censuses' district panel from 1994-2012, I estimate a fixed effects model of the effect of climate variability on crop portfolio decisions. According to the study's findings, an increase in intraseasonal climate variability (30-year average temperature range during the first trimester of the rainy season) affects colder and warmer areas in the Andean region differently. Furthermore, there is evidence of omitted sub-region-relevant variables, and thus of heterogeneity in climate effects between the Northern, Central, and Southern sub-regions.

This study finds that, ceteris paribus, an increase in intraseasonal 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 intraseasonal climate variability across the temperature gradient. Assuming that no interventions take place, the findings show that an increase in intraseasonal climate variability in cold areas (with average temperatures below 11°C during the growing season) would lead farmers to concentrate their crop portfolio with 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 and more extreme temperatures.

The lack of statistically significant effects in crop portfolio concentration and tolerance in Northern and Central regions is consistent with results from a previous study (Ponce 2018), which found that rural households tend to respond to increases in intraseasonal climate variability by increasing non-farm income shares and non-farm hours shares in these two regions. These increasing shares of non-farm income sources is explained by increasing non-farm income levels, with no significant changes in farm income level. Southern rural households, on the other hand, showed a statistically insignificant negative effect on non-farm income shares (Ponce 2018). The present study also contributes to our understanding of the response of these farmers to increasing climate variability. Even though no significant changes in non-farm income shares were found by Ponce (2018) for the Southern region, significant changes were predicted for on-farm production decisions that would help maintain production and income levels by slightly increasing the number of hours devoted to farm work. At the same time, on-farm income and work in the previous study (Ponce 2018) included not only cropping activities (analyzed in the present study) but also pastoral activities, which play a key role in the Puna region (coldest and highest areas of the Southern and Central Andes).

This study provides evidence regarding the type of adaptation strategies that Andean farmers tend to implement when facing increasing intraseasonal climate variability, especially in the Southern Andes: increasing crop portfolio concentration towards crops that seem to be more tolerant to diverse climate conditions, while reducing the land share allocated to intercropping practices. As previously discussed, intercropping practices can be effective for pest and disease control when adequately implemented. However, identifying the combinations of crops (and varieties) that may be most adequate for the new environmental conditions that climate change as well as other global and local changes bring about in the Andean region is still a pending agenda. Furthermore, Andean farmers require information, inputs, and technical assistance to adapt their current intercropping practices to the changing environmental conditions.

In conclusion, more 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 (Dourojeanni et al. 2016). 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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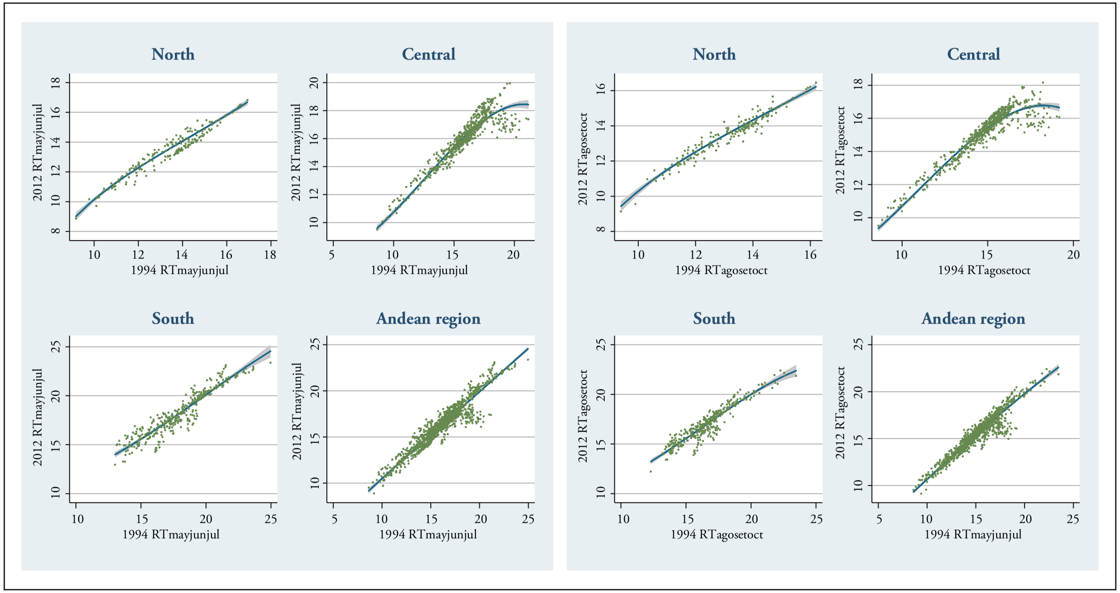
ANNEX

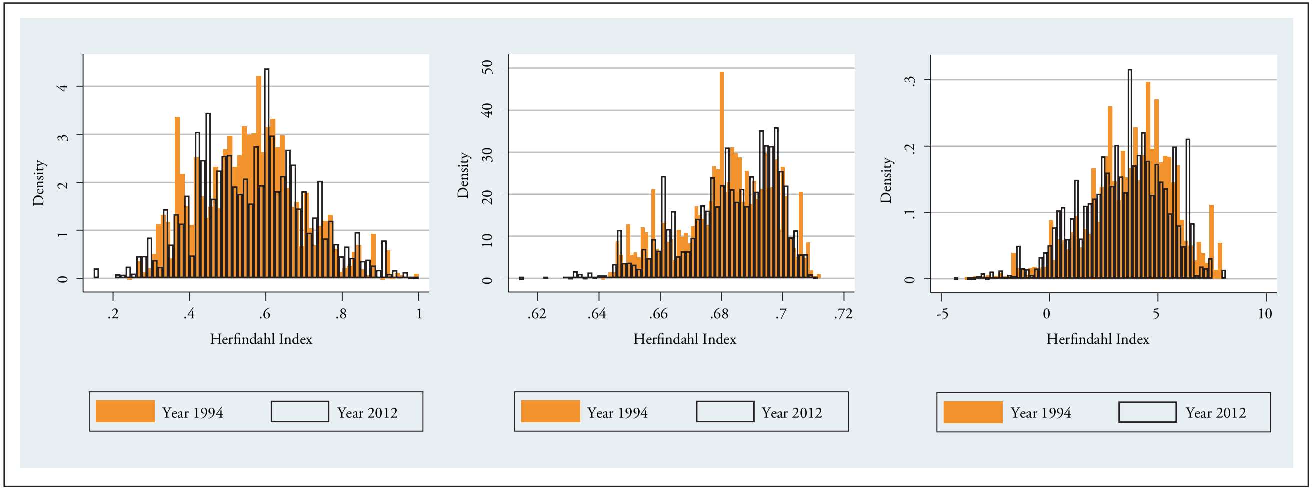
Graph A1.

Patterns of change in intraseasonal temperature range during dry trimesters (May-July and August-October), by sub-region.



Note: The curve is a fractional polynomial fit, weighted by the district's cultivated area in the Andean region. The dots represent the observations for each district.

Graph A2
Distribution of the Herfindahl index, Multisite index, and Intercropping land in the Andean region, by year.



Note: The Herfindahl and Multisite indices were calculated at the farm level and then aggregated at the district level as averages weighted by the farm's cultivated area. The area with intercropping was calculated as the total cultivated area in the district where intercropping was used.

Table A3.1.

Marginal effect of climate conditions on crop portfolio decisions (only statistically significant effects are shown)

	Herfindahl index (degree of crop concentration)	Multisite index (relative tolerance to environmental diversity)	Cultivated land allocated to intercropping
Andes			
Intraseasonal climate variability		0.002 **	-1.2 ***
Average temperature	0.1 **	0.006 *	-2.1 **
Precipitation			
% farmers with irrigation system	-0.1 *		1.9 **
Northern Andes			
Intraseasonal climate variability		-1.3 '	
Average temperature		-4.6 ''	
Precipitation	-0.006 *		0.15 ***
% farmers with irrigation system	-0.3 ***		
Central Andes			
Intraseasonal climate variability		-2.2 *	
Average temperature	0.15 ***	-0.3 *	
Precipitation		2.5 *	
% farmers with irrigation system			
Southern Andes			
Intraseasonal climate variability	0.06 **	0.003 **	-1.6 ***
Average temperature	0.15 *		
Precipitation			
% farmers with irrigation system			

*** p<0.01, ** p<0.05, * p<0.1. Marginally significant estimates: ' pvalue 0.175; '' pvalue 0.135.

Table A4.1.
Effects of climate on concentration - Herfindahl (weighted by cultivated area, robust)

	(1)	**(2)**	**(3)**	**(4)**
VARIABLES	**Andes**	**North**	**Central**	**South**
30-year average temperature (Nov/Dec/Jan) (ii)	0.249***	-0.190	0.110	0.276**
	(0.089)	(0.351)	(0.131)	(0.131)
30-year temperature range (Nov/Dec/Jan) (i)	**0.092**	-0.302	0.102	**0.160****
	(0.102)	(0.323)	(0.084)	(0.079)
(i)*(ii)	-0.011**	0.016	-0.009	-0.009
	(0.004)	(0.023)	(0.007)	(0.006)
(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	-0.003
	(0.001)	(0.004)	(0.001)	(0.003)
The household has some type of irrigation system (gravity, aspersion, dripping, or other)	-0.097*	-0.310***	-0.081	-0.056
	(0.053)	(0.109)	(0.075)	(0.112)
Dummy of year (2012)	-0.004	0.031	0.115*	-0.267***
	(0.039)	(0.095)	(0.064)	(0.074)
Sex of household head (1=male)	0.101	0.641***	0.092	-0.377*
	(0.105)	(0.217)	(0.167)	(0.193)
Age of household head	-0.001	0.011	-0.013**	0.020***
	(0.003)	(0.007)	(0.006)	(0.006)
Number of household members	-0.031**	-0.042	-0.026	-0.027
	(0.015)	(0.028)	(0.025)	(0.026)
Household head graduated from primary school or higher	-0.096	0.616***	-0.387**	0.571***
	(0.120)	(0.231)	(0.188)	(0.208)
Farms that have access to at least one concrete-lined irrigation canal	0.089	0.244	0.160**	0.001
	(0.058)	(0.235)	(0.077)	(0.089)
Land Gini coefficient (equivalent hectares) - Province	-0.402***	-0.471**	-0.157	-0.408***
	(0.069)	(0.236)	(0.112)	(0.127)

▶

VARIABLES	(1) Andes	(2) North	(3) Central	(4) South
% of farmers that diversify into non-farm activities - Province	0.045	0.117	0.045	0.108
	(0.062)	(0.188)	(0.134)	(0.109)
% of cultivated area with mechanized agriculture (tractor) - Province	0.141**	-0.005	0.219**	0.146
	(0.064)	(0.234)	(0.086)	(0.097)
% of farms using certified seeds - Province	0.089	-0.721*	0.235	0.243
	(0.131)	(0.404)	(0.251)	(0.194)
% of farms that received technical assistance - Province	-0.065	-0.424	0.630	-0.235
	(0.178)	(0.691)	(0.414)	(0.168)
% 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)	0.030	0.045	0.014	-0.022
	(0.043)	(0.195)	(0.054)	(0.067)
Constant	-2.133*	4.205	0.253	-3.383*
	(1.247)	(5.477)	(1.655)	(1.783)
Observations	2336	382	1240	714
R-squared	0.154	0.319	0.149	0.323
Number of districts æ	1,168	191	620	357
N	2336	382	1240	714
F	5.507	4.414	2.264	7.091
Haussman specification test				
Chi2(17)[a]	115.14	54.07	81.57	49.96
Prob>chi2	0.00	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.

[a] Chi2(19) for the Andean region column.

Table A4.2.
Effects of climate on concentration - Multisite index (weighted by cultivated area, robust)

VARIABLES	(1) Andes	(2) North	(3) Central	(4) South
30-year average temperature (Nov/Dec/Jan) (ii)	0.013**	0.024	0.014**	0.011
	(0.006)	(0.027)	(0.007)	(0.007)
30-year temperature range (Nov/Dec/Jan) (i)	0.014**	0.019	0.001	0.012*
	(0.006)	(0.021)	(0.004)	(0.006)
(i)*(ii)	-0.001	-0.001	0.000	-0.001
	(0.000)	(0.001)	(0.000)	(0.001)
(i)*Dummy for Central Andes	-0.006*			
	(0.003)			
(i)*Dummy for Southern Andes	-0.005			
	(0.003)			
30-year average precipitation (Nov/Dec/Jan)	0.000	-0.000	0.000	0.000
	(0.000)	(0.000)	(0.000)	(0.000)
The household has some type of irrigation system (gravity, aspersion, dripping, or other)	0.002	0.002	0.010	-0.002
	(0.005)	(0.011)	(0.006)	(0.004)
Dummy of year (2012)	-0.004	0.013*	-0.009***	-0.001
	(0.003)	(0.008)	(0.003)	(0.004)
Sex of household head (1=male)	-0.009	0.006	0.004	-0.029***
	(0.007)	(0.015)	(0.009)	(0.010)
Age of household head	0.000	-0.000	0.000*	-0.000
	(0.000)	(0.001)	(0.000)	(0.000)
Number of household members	0.001	0.001	0.000	0.001
	(0.001)	(0.002)	(0.001)	(0.001)
Household head graduated from primary school or higher	0.012*	-0.015	0.021***	-0.011
	(0.007)	(0.019)	(0.008)	(0.009)
Farms that have access to at least one concrete-lined irrigation canal	-0.004	-0.002	-0.002	-0.006**
	(0.003)	(0.018)	(0.004)	(0.003)
Land Gini coefficient (equivalent hectares) - Province	0.013***	-0.017	0.002	0.017***
	(0.004)	(0.017)	(0.006)	(0.006)
% of farmers that diversify into non-farm activities - Province	-0.002	-0.031**	0.008	-0.010
	(0.004)	(0.015)	(0.006)	(0.007)

▶

VARIABLES	(1) Andes	(2) North	(3) Central	(4) South
% of cultivated area with mechanized agriculture (tractor) - Province	0.005	-0.005	-0.011*	0.012***
	(0.003)	(0.016)	(0.005)	(0.004)
% of farms using certified seeds - Province	-0.010	0.011	-0.017	-0.006
	(0.007)	(0.028)	(0.011)	(0.010)
% of farms that received technical assistance - Province	0.015*	0.024	-0.022	0.021**
	(0.009)	(0.048)	(0.021)	(0.011)
% 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)	0.007***	0.010	0.007**	0.005**
	(0.002)	(0.014)	(0.003)	(0.003)
Constant	0.473***	0.365	0.463***	0.525***
	(0.081)	(0.409)	(0.091)	(0.090)
Observations	2316	372	1232	712
R-squared	0.086	0.156	0.152	0.283
Number of districts æ	1,158	186	616	356
N	2316	372	1232	712
F	2.939	1.855	2.410	7.097
Haussman specification test				
Chi2(17)[a]	289.46	27.89	66.49	275.28
Prob>chi2	0.000	0.0463	0.000	0.000

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.

The higher the Multisite index, the higher the average ecological niche (the higher the crops' average tolerance to a wider range of environmental conditions).

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.

[a] Chi2(19) for the Andean region column.

Table A4.3.
Effects of climate on intercropping (weighted by cultivated area, robust)

VARIABLES	(1) Andes	(2) North	(3) Central	(4) South
30-year average temperature (Nov/Dec/Jan) (ii)	-3.908***	-8.619**	-2.718	-2.560
	(1.352)	(4.246)	(1.797)	(1.997)
30-year temperature range (Nov/Dec/Jan) (i)	-3.402**	-6.308	-0.871	-3.872**
	(1.526)	(4.034)	(1.231)	(1.745)
(i)*(ii)	0.141	0.351	0.039	0.213
	(0.088)	(0.272)	(0.106)	(0.142)
(i)*Dummy for Northern Andes	0.000			
	(0.000)			
(i)*Dummy for Central Andes	1.292			
	(0.809)			
(i)*Dummy for Southern Andes	-0.145			
	(0.805)			
30-year average precipitation (Nov/Dec/Jan)	-0.014	0.145***	-0.030*	-0.022
	(0.015)	(0.046)	(0.017)	(0.042)
The household has some type of irrigation system (gravity, aspersion, dripping, or other)	1.906** (0.949)	2.691 (1.776)	2.457* (1.302)	0.081 (1.592)
Dummy of year (2012)	-1.171**	-3.929***	-0.971	-0.934
	(0.583)	(1.163)	(0.725)	(1.447)
Sex of household head (1=male)	-4.262***	-2.850	-6.135**	-1.416
	(1.375)	(2.253)	(2.418)	(2.773)
Age of household head	-0.007	0.047	0.071	-0.057
	(0.039)	(0.077)	(0.059)	(0.097)
Number of household members	0.089	-0.382	-0.096	0.602
	(0.205)	(0.330)	(0.323)	(0.433)
Household head graduated from primary school or higher	8.045*** (1.817)	8.091** (3.209)	10.959*** (2.896)	5.347 (3.689)
Farms that have access to at least one concrete-lined irrigation canal	0.109 (1.110)	-2.325 (3.508)	-1.910** (0.879)	2.360** (1.055)
Land Gini coefficient (equivalent hectares) - Province	-2.194** (1.100)	2.402 (2.652)	-4.739*** (1.464)	-1.466 (1.899)

►

	(1)	(2)	(3)	(4)
VARIABLES	**Andes**	**North**	**Central**	**South**
% of farmers that diversify into non-farm activities - Province	1.853*	1.988	-2.146	2.955*
	(1.045)	(2.191)	(1.873)	(1.695)
% of cultivated area with mechanized agriculture (tractor) - Province	-0.735	0.817	-1.384	-0.159
	(0.758)	(2.331)	(1.092)	(1.345)
% of farms using certified seeds - Province	-5.906***	0.757	-4.327*	-8.635***
	(1.586)	(5.088)	(2.499)	(2.733)
% of farms that received technical assistance - Province	-2.987	-9.320	-2.792	-2.473
	(2.463)	(6.499)	(4.748)	(3.200)
% 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)	-0.758	-1.708	0.750	-1.148
	(0.602)	(1.803)	(0.703)	(0.810)
Constant	69.339***	130.597*	45.460**	55.370*
	(18.502)	(66.951)	(22.833)	(28.232)
Observations	2140	366	1121	653
R-squared	0.209	0.455	0.262	0.255
Number of districts æ	1,148	191	610	347
N	2140	366	1121	653
F	8.043	7.581	9.648	3.285
ll	-3086	-414.1	-1601	-950.9
Haussman specification test				
Chi2(17)[a]	85.21	52.6	50.1	45.74
Prob>chi2	0.000	0.000	0.000	0.0002

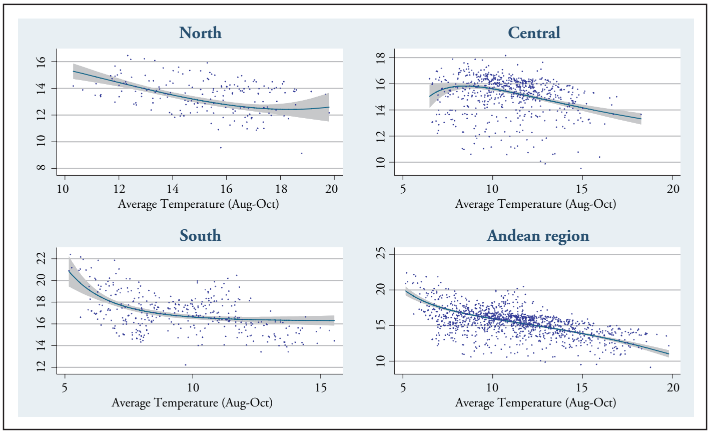
Fixed effects estimates: District observations weighted by corresponding cultivated area. Robust standard errors in parentheses (adjusted to account for potential heteroscedasticity), *** p<0.01, ** p<0.05, * p<0.1.

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.

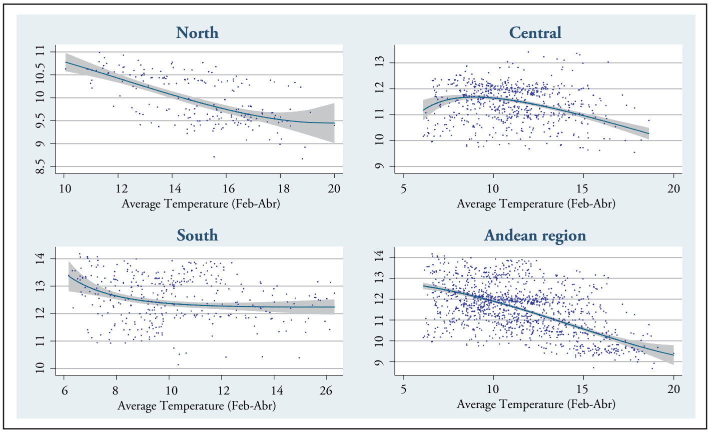
[a] Chi2(19) for the Andean region column.

Graph A5.
Average temperature and temperature range in 2012, by sub-region

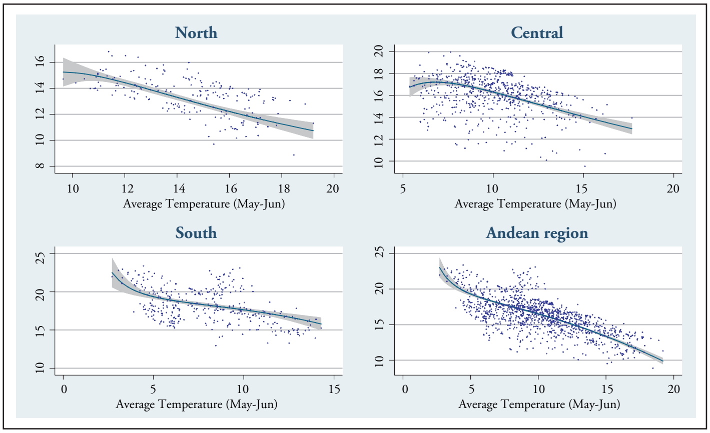
a. August-October trimester (start of the agricultural calendar)



b. February-April trimester



c. May-July trimester



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Edits completed in May 2018.