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# Weather shocks and their effects on net agrarian revenue in small and medium-size farm in Peru

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# Contents

# List of Tables



# List of Figures



# List of Equations

# List of Appendices

# List of Acronyms

| | |
|---|---|
| CENAGRO | Censo Nacional Agrario (National Agrarian Census) |
| ENA | Encuesta Nacional Agraria (National Agrarian Survey) |
| ENSO | El Niño-Southern Oscillation |
| GIS | Geographic Information Systems |
| GPS | Global Positioning System |
| IHS | Inverse Hyperbolic Sine |
| INEI | Instituto Nacional de Estadistica e Informatica (National Institute of Statistics and Informatics) |
| RCP | Representative Concentration Pathways |
| USA | United States of America |

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## Abstract

This study explores the effect of weather shocks (temperature and precipitations) on net agrarian revenue in small and medium-size farms in Peru. The paper used Geographic Information Systems data of weather variables combined with agrarian information of more than 68,000 households from the National Agrarian Survey of the period 2015-2017.

The results suggest that there is a negative effect of the temperature deviation of -6.7 percentage points over the annual net agrarian revenue per hectare. In addition, the study does not find a statistically significant effect of the precipitation deviation. Results are robust to different specifications and inclusion of outliers. The estimated effects on this paper are similar than those estimated by Seo and Mendelsohn (2007) for small farms in Latin America.

The study finds regional differences. On the Coast, the effect of temperature on net agrarian revenue is 9.9 percentage points, in the Rainforest 4.3 and no effects in the Highland. The latter is consistent with the literature that states that in cold zones the temperature have either small or no effect (Seo, Mendelsohn and Munasinghe, 2005; Mendelsohn and Reinsborough, 2007). Finally, using the 4 RCP scenarios of the IPCC (2014), the paper estimates that by the end of the 21st century the losses in the annual net revenue per hectare for the small and medium size farms in Peru could be between 11.8 and 43.5 percentage points.

## Relevance to Development Studies

Facing the consequences of climate change is one of the most critical challenges of humanity in our time. This phenomenon is expected to increase weather shocks and affect specific economics sectors to a greater extent. Since agriculture is directly dependent on climate, it is expected to be one of the most affected activities. In that sense, knowing the effects of current weather shocks on farmers is a necessary first step in designing public policies to address this situation. This paper seeks to generate evidence in that direction focusing on Peru, a country with a high percentage of the population dedicated to agriculture and a high level of poverty among producers.

### Keywords

Weather, agriculture, smallholders, agrarian revenue, Ricardian.

# Chapter 1
# Introduction

Climate change is a phenomenon that can affect people's lives, as it has the power to transform or change the physical and human geography of the planet, through changes in temperature and precipitation, and even cause natural disasters (PNUD, 2013; Gorst, Dehlavi and Groom, 2018). In the context of this type of transformation, certain activities are more vulnerable, like agriculture (Brown and Funk, 2008; Choudhary, Kumar and Singh, 2019).

Considering that the vast majority of farmers in developing countries consume what they produce, it can be said that a large percentage of the population in developing countries live in a situation of food insecurity, because, with changes in temperature and rainfall, production may decrease and this is likely to have a direct effect on their food consumption (Brown and Funk, 2008). In addition, changes in climate can negatively impact the possibility of bringing agricultural surpluses to market, as the costs associated with agricultural production are likely to increase (Schmidhuber and Tubiello, 2007).

Various studies have affirmed that Peru is one of the most vulnerable countries to climate change (Nakicenovic *et al.*, 2000; Brooks and Adger, 2003; Stern, 2007). A clear example of this was the ENSO[1] phenomenon in 2017. According to the commission in charge of studying the phenomenon, the ENSO of that year was the third most intense in at least the last one hundred years for Peru (ENFEN, 2017). As a consequence of the phenomenon, there were landslides, heavy rains, and electrical storms. The losses in the agricultural sector were approximately USD 700 million (Angulo, 2017).

There is a direct relationship between weather and climate. The first concept can be understood as atmospheric variations in temperature, humidity, and precipitation over a short duration (hours, days) in a specific region, the second can be understood as an average of weather variations over a longer duration (years, centuries) (Lazzaroni, 2012). Therefore, "weather variability can be considered ultimately a signal of climate change to the extent that it departs from the average prevalent atmospheric condition measured in the past and it is a source of change in the long-term pattern of climate for the location considered"(Lazzaroni, 2012, p. 1)

This research paper, which focuses on Peru, explores the link between weather variations (precisely temperature and precipitation) and the revenues of smallholders based on a nationally representative household agricultural survey and climate data obtained from Geographic Information Systems (GIS). The novelty of the study is that it is the first (to my knowledge) to use the Ricardian model to estimate the impacts of climate variations in Peru. Although there are estimates of the impact of climate changes on Peruvian agriculture that do not use a Ricardian model (detailed in chapter 4). Those studies do not take into account the responses of producers because they only look at a specific crop instead of looking at the entire farm. In that sense, the existing literature may provide an incomplete picture of the impact of climate change. Finally, the use of a new national agricultural survey (detailed in chapter 5) is relevant. This survey has a lower level of spatial disaggregation than that used in previous work so that temperature and precipitation data may be assigned more accurately to the producer.

The relevance of the research is also sustained by the importance of farming activity in Peru. According to the last agricultural census carried out in 2012, there are 2 million 213 thousand agrarian units (farming families) in the country. The average size of these households is 3.4 members so that in total, approximately 7.5 million people are members of farming households, representing 25% of the entire population of the country. Of the producers, 98% are small and medium-sized farmers (less than 50 hectares)[2], and 54% of the agricultural area is held by these producers (INEI, 2013; Eguren López, 2015).

Against this background, this research paper seeks to answer the following question:

> What is the effect of variations in temperature and precipitation on the net agrarian revenue of small and medium farmers in Peru?

As a sub-question, this paper attempts to respond to the following question "Are there differentiated effects based on the natural region in which the producers are located?". This question arises due to the heterogeneity of both agrarian dynamics and weather in the different regions of Peru, as can be seen in the following chapters.

The rest of the document is organized as follows. The next chapter presents some characteristics of the Peruvian agrarian sector, emphasizing the differences across natural regions. The third chapter introduces a theoretical framework to model the effect of weather on farmers' production. The fourth chapter presents a review of the existing empirical evidence. The fifth presents the data sources that are used, as well as a descriptive statistics analysis. The sixth chapter presents the methodology, while the seventh chapter presents the results and the eighth the conclusions and limitations of the paper.

# Chapter 2
# Peruvian Agrarian Dynamics

This chapter presents the main characteristics of Peru's agricultural sector. The aim is to put into context the results that are presented later in the paper. Explicitly this chapter addresses three points: i) There is a strong concentration of agrarian land in Peru, ii) There is diversity of crops which depends on the natural regions, and iii) There are diverse agronomic characteristics in each of the natural regions.

This chapter relies on two data sources. These are the latest national agrarian census (CENAGRO by its acronym in Spanish) and the *Harmonized World Soil Database v 1.2* (Fischer *et al.*, 2008). Before proceeding to the analysis, it is essential to mention that Appendix 1 shows a map of the natural regions of Peru. This comes from the geo-referenced data of CENAGRO and will be the definition of natural region used in this study.

Table 2-1 shows the number of producers according to their legal status and the region in which they are located.

**Table 2-1: Number of producers by region**

| | Coast | Highlands | Rainforest | Total |
|---|---|---|---|---|
| Farmers | 354,295 | 1,435,657 | 456,750 | 2,246,702 |
| Business | 2,459 | 380 | 233 | 3,072 |
| Communities | 226 | 5,941 | 1,432 | 7,599 |
| Others | 581 | 2,552 | 467 | 3,600 |
| Total | 357,561 | 1,444,530 | 458,882 | 2,260,973 |

Source: Author's elaborations based on CENAGRO 2012

As can be seen, there are differences both by natural region and by the legal status of the producer. As far as the natural region is concerned, there are many producers located in the Highland region, approximately 63% of all producers. It can also be observed that most producers are farmers (99%). Access to land is quite uneven, as shown in table 2-2.

**Table 2-2: Average land size (ha)**

| | Coast | Highlands | Rainforest | Total |
|---|---|---|---|---|
| Farmers | 3.9 | 5.7 | 9.8 | 6.3 |
| Business | 171.6 | 404.1 | 505.8 | 225.7 |
| Communities | 11,038.8 | 2,284.3 | 5,167.4 | 3,088.0 |
| Others | 275.1 | 114.8 | 39.3 | 130.9 |
| Total | 12.4 | 15.4 | 26.2 | 17.1 |

Source: Author's elaborations based on CENAGRO 2012

An analysis of farmers shows that there are differences in the average size of landholdings according to the natural region. The average area in the Rainforest is much higher than in the other two regions. This is mainly because, in this region, there is no clear delimitation of the private area, and in many cases the producers assume that they own forest lands.

Analyzing the sizes according to the legal status of producer shows more substantial differences. The average of an agricultural unit for farmers of 6.3 hectares, while for business is 2255.7 hectares and for communities of 3,088 hectares. The size of the communities is expected, as it is an area shared by several families. However, the differences in size between households and businesses show a significant concentration of land in Peru.

The land concentration phenomenon can also be analyzed through the Gini index[3]. As shown by Bourliaud and Eresue (2015), land concentration is quite high in Peru during the whole period for which data are available, as can be seen in table 2-3.

**Table 2-3: Gini index of land**

| Census | 1961 | 1972 | 1994 | 2012 |
|---|---|---|---|---|
| Index | 0.93 | 0.90 | 0.88 | 0.93 |

Source: Bourliaud and Eresue (2015)

According to Guereña (2016), the average Gini index of land concentration is 0.57 in Europe, 0.56 in Africa 0.55 in Asia, 0.75 in Central America, and 0.85 in South America. Peru is above the average for South America, the most unequal region in terms of access to land. It can be seen that the Gini index had a low point in 1994. This could be explained by the agrarian reform that took place during the 1970s. (Mattos Mar and Mejia, 1980; Mayer, 2009). However, the last census shows that land concentration has increased again, over the last few years, probably due to the concentration of land held by agribusiness companies (Bourliaud and Eresue, 2015) and because of the divisions due to inheritance[4] (Remy, 2012).

Another essential aspect that is shown by the CENAGRO is the diversity of crops according to the natural region. Using as a variable the sown area, table 2-4 shows the five main crops by region and their weight in relation to all crops. It is important to note that this table contains information only from farmers who have less than 50 hectares in total, as this is the reference population of the study, as will be seen below.

**Table 2-4: Main crop by region**

| Crop | Percentage |
|---|---|
| **Coast** | |
| Hard yellow corn | 14% |
| Rice | 10% |
| Alfalfa | 6% |
| Sugar cane | 5% |
| Cotton | 4% |
| **Highland** | |
| White potato | 15% |
| White corn | 11% |
| Alfalfa | 10% |
| Native Corn | 5% |
| Coffee | 4% |
| **Rainforest** | |
| Coffee | 28% |
| Cocoa | 10% |
| Banana | 9% |
| Hard yellow corn | 8% |

| | |
|---|---|
| Rice | 6% |

Source: Author's elaborations based on CENAGRO 2012

The main crops grown in each natural region are quite different. For instance, in the Rainforest the main crop, coffee, represents 28% of all sowed area, and its five main crops account for 61% of the sown land. In the Highlands and the Coast, the concentration is lower, as the five main crops account for 46% and 38% of the total area sown, respectively.

The database of Fischer *et al.*, (2008) provides information on differences in the quality of soil. This is a georeferenced base and has a detail of 0.01 degrees (approximately 0.5 square kilometers on the equatorial line), so the same procedure had to be followed as with the weather bases (these are described in chapter 5.4). Table 2-5 shows what percentage of surface of each of the regions has no limitations[5] across seven soil characteristics. No limitations mean that the soil is well-endowed in that attribute.

**Table 2-5: Soil quality per region**

| Variable | Coast | Highlands | Rainforest | National average |
|---|---|---|---|---|
| No limitations: Nutrient availability | 26% | 40% | 20% | 33% |
| No limitations: Nutrient retention capacity | 51% | 70% | 41% | 60% |
| No limitations: Rooting conditions | 51% | 23% | 65% | 38% |
| No limitations: Oxygen availability to roots | 86% | 97% | 74% | 90% |
| No limitations: Excess salts | 66% | 97% | 98% | 92% |
| No limitations: Toxicity | 98% | 98% | 98% | 98% |
| No limitations: Workability (constraining field management) | 38% | 23% | 59% | 34% |

Source: Author's elaborations based on Fischer *et al.*, (2008)

It can be observed that the Highland region has a higher percentage of the surface without limitations in the categories of availability and retention of nutrients, as well as availability of oxygen for the roots. The Rainforest region has better root and salt conditions, as well as workability.

This chapter has shown that there is a large difference between the size of the land of industrial producers (businesses) and farmers. There is also an increase in the inequality of access to land between the last two CENAGROs. This suggests an increase in the vulnerability of small and medium producers. On the other hand, it has been seen that there are differences in crops and land conditions across natural regions. The latter justifies the attempt to identify heterogeneous effects across natural regions since these differences can affect the relationship between weather shocks and agrarian revenue.

# Chapter 3
# Theoretical Framework

There is abundant literature on how to approach the relation of the agrarian or peasant economy and weather. It is possible to divide the theoretical models into two subtypes. One approach focuses on production functions, which includes weather as one of the production factors. In this type of model, a production function may be specified as the following equation:

**Equation 3-1: Production function**

$$Y_x = F(W, C, X)$$

In equation 3-1 $\boldsymbol{Y}$ represents the productivity per hectare of crop $\boldsymbol{x}$. $\boldsymbol{F(.)}$ represents a production function that depends on $\boldsymbol{W}$, inputs, $\boldsymbol{C}$ weather variables, and $\boldsymbol{X}$ represents the characteristics of the producer.

The second approach was developed by Mendelsohn, Nordhaus and Shaw (1994), and it is called the Ricardian or hedonic approach. Its name comes from David Ricardo's observation that the value of land reflects its productivity (Mendelsohn and Reinsborough, 2007). Due to this, the original model equates the value of land to its productivity which must be equal to the net present value of revenues per hectare.[6] Its main advantage over the traditional approach is that "the method not only includes the direct effect of weather on productivity, but also the adaptation response by farmers to local weather." (Seo, Mendelsohn and Munasinghe, 2005, p. 583). Blanc and Reilly (2017) claim that the use of revenues can capture more fully the adaptation measures of small producers than crop yields[7].

As can be seen in chapter 4, the first studies that used this conceptual framework were conducted in developed countries. This may be attributed to the availability of data on the dependent variable, that is, the value of land. Mendelsohn and Dinar (2009) suggest that using net revenue per hectare in the context of developing countries since the lack of a dynamic land market does not permit the use of e real values of the land[8]. Additionally, and advantage of using the agrarian revenue instead of the value of land is that farms that are near urban areas tend to have an inflated price (because of the potential development value). In that sense, farm values can overestimate the productive potential of the farm (Mendelsohn and Massetti, 2017).

Following the work of Huong, Bo and Fahad (2018) and Mendelsohn and Dinar (2003), it is possible to model the net revenue function of the farmer, $\pi$, as

**Equation 3-2: Net agrarian revenue in the Ricardian model**

$$\pi = \sum PC_i \, Q_i(W, C, X) - \sum PI_i \, W$$

Where the subscripts $\boldsymbol{i}$ represents the farmers, $\boldsymbol{PC}$ the prices of the crops, $\boldsymbol{Q}$ the production, $\boldsymbol{PI}$ the prices of the inputs. As in equation 3-1 production is a function of inputs, a set of weather variables, and a set of characteristics of the farmer.

Since prices, weather variables, and producers' variables are fixed, the optimal net revenue function results in:

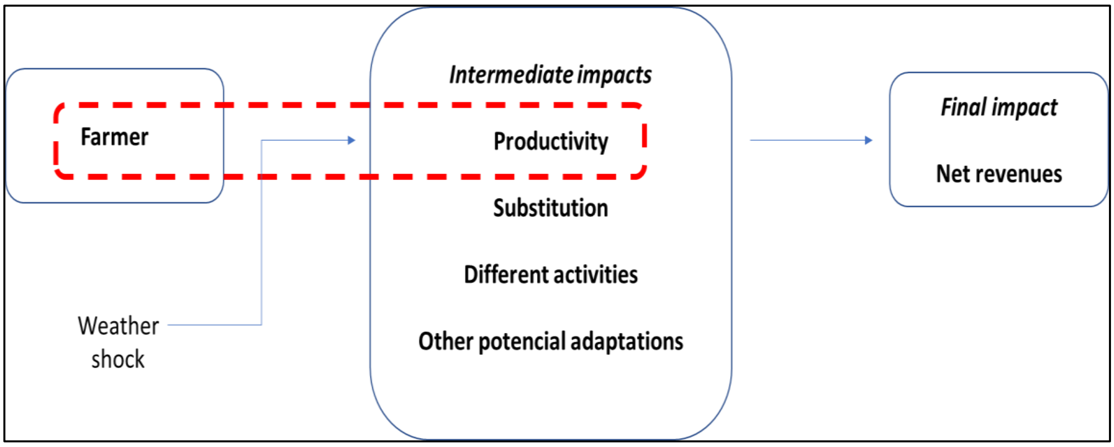
**Equation 3-3: Optimization function under the Ricardian model**

$$\pi^* = f\ (W \mid P, X, C)$$

From the above relationship, it can be understood that producers chose the optimal level of input (and therefore of production) given a set of prices, their characteristics, and weather. As will be seen in the next chapter, this conceptual model has been used in several empirical studies that have analyzed the relationship between weather variability and agriculture.

As a summary, image 3-1 shows how the Ricardian model extends the traditional model of measuring the relationship between weather and agricultural dynamics.

**Figure 3-1: Traditional and Ricardian approach**




Source: Author's elaborations based on Seo, Mendelsohn and Munasinghe, 2005.

In the image above, the relationship that is studied by the traditional model is marked in red. As can be seen, this approach omits other impacts of weather shocks, such as crop substitution, change of activities, and measures of adaptation of producers. It is all these impacts that generate the value of net agrarian revenue. For this reason, this paper uses the Ricardian model as the basis of the analysis, as can be seen in the following chapters.

# Chapter 4
# Previous Empirical Evidence

This chapter is divided into two subchapters. The first one reviews some empirical evidence of studies that have used the Ricardian model in different contexts. The second subchapter presents empirical evidence on weather variability and agriculture in Peru.

## 4.1 International empirical evidence

The first part of this subchapter describes different papers that use the Ricardian model, while the second part discusses some critical aspects of the studies and how this paper fits into the literature. The selection of papers in this section responds to the objective of showing the differences in the studies, in terms of methods used, as well as in variables of interests and countries or areas studied.

As already mentioned, the Ricardian model for measuring the effects of weather on agriculture was conceptualized by Mendelsohn, Nordhaus and Shaw, (1994). The paper uses cross-sectional data from the United States of America (USA) and estimates that in that country an increase of 5 degrees Fahrenheit (2.7 degrees Celsius) would have a negative impact of 4-6% of farm value.

Schlenker, Hanemann and Fisher (2005), replicate the paper and find that the negative effects persist but only for the dry areas, but do not find effects in the irrigation areas. Schlenker, Hanemann and Fisher (2006), made a new cross-sectional estimate for the USA. In the paper, the authors correct the model by spatial correlation. In this new model they find that the farm value has a negative elasticity of 10-25% (depending on the specification).

Two additional studies have focused on North America. Mendelsohn and Reinsborough (2007), made a cross-sectional study of the USA and Canada. In the paper, the authors mention that there are negative effects of temperature in the USA (elasticity of -2.8 over the farm value) but not in Canada. They also find positive effects of precipitation in both countries (elasticity of 2.2 in Canada and 0.8 in the USA, on the farm value). The paper emphasizes how temperature does not affect cold areas (Canada). Finally, Deschênes and Greenstone (2007), make a study in USA using a fixed effects model (at the level of years). Unlike the previous studies, the authors found positive effects of the temperature on the farm value of 4%.

On the side of studies done in developing countries, Seo, Mendelsohn and Munasinghe (2005), made a cross-sectional study in Sir Lanka. In that paper, the dependent variable was agricultural revenue. The authors estimate a negative effect of temperature of 7 percentage points in the tropical region of the country, but no effect in the Highlands.

Kurukulasuriya *et al.* (2006), made a cross-sectional work in eleven African countries[9]. Estimating a fixed-effects model at the country level and using agricultural revenue as a dependent variable, the authors find a negative effect of the temperature in the dry land (elasticity of -1.1) and a positive effect of the precipitation in the irrigation lands (elasticity of 0.3). In the same line, Seo and Mendelsohn (2007) perform a cross-sectional study in seven Latin American countries (not including Peru)[10]. As a dependent variable the authors use both the farm value and the net revenue. The paper estimates a negative effect of temperature (-2.8 elasticity) on small farms (less than 30 hectares).

Finally, the study of Sanghi and Mendelsohn (2008) analyzes the effect of weather on the agrarian revenue and farm value in Brazil and India. For that, the authors use a region and year fix effect model. Negative temperature effects are found in both countries (elasticities of -6.4 and -9 in Brazil and India, respectively). There is also a negative effect of precipitations in Brazil (elasticity of -5.4) and a positive effect in India (elasticity of 1).

Four main ideas can be highlighted from the studios. Firstly, there may be heterogeneous effects of the weather depending on the agrarian dynamics. In the same country (or contiguous countries), the effects can have a different magnitude or even be present only in some regions and not in others (Kurukulasuriya *et al.*, 2006; Mendelsohn and Reinsborough, 2007; Huong, Bo and Fahad, 2018). This enhances the importance of the subquestion in this paper.

Secondly, along with the previous point, the literature shows that the effects of temperature in cold areas are less than in other areas (Seo, Mendelsohn and Munasinghe, 2005) or non-existent (Mendelsohn and Reinsborough, 2007). Since Peru has a region with this type of weather (the Highlands), it would be expected to find a different dynamic to the rest of the country in this natural region.

Thirdly, omitted variables may change (or vanish) the effects of cross-sectional studies. This is illustrated by comparing the studies of Mendelsohn, Nordhaus and Shaw, (1994) and Schlenker, Hanemann and Fisher (2005). The first study does not include any variable to control the effect of access to irrigation and finds an overall negative effect of temperature. The second controls access to irrigation (then divides the sample into irrigated areas and dry areas) and find effects only for dry areas.

The problem of omitted variables in cross-sectional studies is also highlighted in the revision of Mendelsohn and Massetti, (2017). The authors state that "the cross-sectional approach is vulnerable to omitting variables that are correlated with both climate and the dependent variable, net revenue, across space" (Mendelsohn and Massetti, 2017, p. 283). To avoid this type of bias that this study uses a panel at the level of geographic areas. This type of model removes the possible bias by omission of time-invariant variables (although they do not remove the possible bias by omission of time-varying variables).

Finally, there are two types of dependent variables, farm value and agrarian revenue. As already mentioned, the use of net revenues is due to the lack of information on the farm value in the absence of a land market. The studies of Seo and Mendelsohn (2007) and Sanghi and Mendelsohn (2008) collect primary information at the farm level and use both variables for the estimations. The two find similar effects regardless of the dependent variable. This paper uses as a dependent variable the agrarian revenue variable due to data availability. As we have seen, this is common in literature and should not affect the results.

## 4.2 Empirical Evidence of Peru

As mentioned in the introduction, to my knowledge, there are no studies that have applied the Ricardian model to measure the effects of weather on Peruvian agriculture. In that sense, this section presents studies that have looked at the relationship between weather and agriculture from an economic perspective.

Ponce, Arnillas and Escobal (2015), study the effects of climate change on the productive strategies of farmers; in particular, they study the use of irrigation and crop diversification. Their results suggest that a reduction in precipitation tends to increase the number of farmers using irrigation and reduces the degree of diversification. On the other hand, an increase in temperature causes an increase in the use of irrigation technologies and the concentration of crops. This study shows that producers have adaptation measures with respect to the climate. This justifies the use of the Ricardian model in the Peruvian context. It also emphasizes the importance of controlling the relationship between weather and income through crop diversification and irrigation.

A subsequent study by Ponce (2018) follows this line of research and seeks to estimate the effect of climatic variability during the sowing period of crops. The author uses the agricultural censuses of 1994 and 2012 for the climatic effects. Additionally, she uses other climatic variables and socio-demographic information as controls. The results show that increases in temperature affect the Andean region differently, due to its heterogeneity. In colder areas, this increase allows farmers to include more tolerant crops in their crop portfolio and reduces the area of intercropped crops. Also, he mentions that he finds a positive but not significant effect on crop concentration. This study adds evidence on the possible heterogeneous effect by regions, especially in the Highlands.

Three studies analyze the effects of climate variability using spatial bases. Andersen *et al.* (2014), focuses on Brazil, Mexico, and Peru and uses a general equilibrium model called The Decision Support System for Agrotechnology Transfer (DSSAT) that uses climate variables as inputs to predict crops as outputs. The study predicts a net loss of $32.3 billion to the Peruvian economy from the impact of climate change based on projections of future temperatures.

Tambet (2018) measures the relationship between weather variability and adaptation and conservation practices. The research shows that following a drought, the uses of fertilizes increase, while the water conservation practices decrease a year of considerable high o lower precipitations.

The third study is carried out by Saldarriaga (2016) and analyses the impact of temperature variability as a consequence of climate change on agricultural productivity of the main crops in each region (that is to say, it makes a traditional analysis explained in chapter 3). For this analysis, he uses climate data at the municipal level and creates a series of indicators based on the standard deviation of the temperature of the year that he analyses concerning a historical average that he defines from 1950 to 2010. His results suggest that an increase of a standard deviation above the historic average temperature of the municipality reduces production per hectare cultivated in 25%-65%. This result is quite considerable, but one should not necessarily expect an effect of this magnitude on net agricultural revenue, as producers may have other adaptation measures (figure 3-1).

As can be seen in chapter 6, this research paper will follow a logic similar to Saldarriaga (2016). However, it differs in the databases used for agricultural activity and most important in the variable to explain. This research paper will use the national agricultural survey that is representative of the agriculture activity in the country, so it should a more exact estimation of the impact of weather change in productivity. Also, following the discussion of the previous chapter, a model will be estimated that seeks to measure the effect of weather shocks on net revenue and not on productivity

It can be observed that there is a gap in the literature, as there are no known studies that have looked at the relationship of weather variations and their effect on agrarian revenue in Peru. This, despite the vulnerability of Peru to this phenomenon, as mentioned in chapter 1. This paper seeks to fill this gap. This is done using a panel (which, as seen, has advantages over cross-sectional studies) and a new survey that is representative of Peru's small and medium producers (which is presented in chapter 5).

# Chapter 5
# Data

This chapter presents the data used in the paper. The chapter is divided into five subchapters. The first subchapter mentions the data sources and the reasons for selecting those. The second subchapter details the characteristics of the data source. The third subchapter explains how the dependent variable (net agrarian revenue) is constructed. The fourth subchapter details the construction of the weather variables. Finally, in the fifth subchapter the producers are characterized according to the control variables of the model.

## 5.1 Data sources

There are three main data sources. The first one is the National Agricultural Survey (ENA, for its Spanish acronym). According to INEI (2017), the target population includes producers who are classified as medium and small agricultural units, excluding agricultural units whose legal status is linked to legal persons: corporations, limited liability companies, individual limited liability companies, agricultural cooperatives, or peasant and native communities. Thus, in the ENA, the target population is limited to natural persons who own agricultural land with a size less than or equal to 50 hectares. In that sense, the survey is representative of small and medium-sized agricultural activity in the country. As was previously mentioned, small and medium producers represent 98% of all producers in Peru.

This survey has been carried out annually since 2014. To increase precision and to be able to estimate the empirical specification that will be presented in chapter 6, a pool of surveys of the years 2015, 2016, and 2017 is constructed.[11] With this survey, it is possible to estimate the net agrarian revenue of the smallholders. The surveys also contain information on the demographic characteristics of the farmers, as well as their agricultural practices, access to credit participation in associations, and ownership of productive assets.

One of the most critical aspects of the survey is that it allows us to know the location of the farmers at a reasonably narrow level of disaggregation. There is information about the district of the farmers, as well as the conglomerate[12] in which the farm is located. This allows us to link other sources of information with the survey.

The sample frame of the survey is the IV CENAGRO 2012 (chapter 2 of this paper was constructed using that census). In this sense, once the expansion factors are used, it can be guaranteed that the information is representative of the entire sector of small and medium producers in Peru. In order to select the producers to be surveyed, a two-step design was used, in which first conglomerates are selected and then producers within them. Also, GPS equipment is used to adequately capture the size of the plots, which reduces measurement errors.

As previously mentioned, Saldarriaga (2016) uses the Encuesta Nacional de Hogares (ENAHO) to estimate the impact of weather shocks on the income of farmers in Peru. Although this survey is representative of rural households in Peru, it is not representative of agricultural households. In this sense, the ENA is a better source of data for the estimate proposed in this paper.

The second data source is the one used to identify weather shocks. This study will focus on two weather variables: temperature and precipitations, as suggested by Auffhammer *et al.* (2011). In that sense, the database used for this purpose is the *Terrestrial Air Temperature and Precipitation:1900-2010 Gridded Monthly Time Series, Version 5.01* (Matsuura and Willmott, 2018). The source provides information to a detail of 0.5 degrees (approximately 28 square kilometers on the equatorial line).

This database is built using information from Lawrimore *et al.*, (2011) and the National Centers for Environmental Information (2017). In that sense, the data source combines information from various weather stations. In order to have information in areas where there are no weather stations, an interpolation process is carried out using information from nearby stations. More information on this process can be found in Matsuura and Willmott (2018) and Matsuura and National Center for Atmospheric Research Staff (2019).

The main advantage of using this source over direct data from weather stations (as many studies using the Ricardian method do) is that it is possible to use all the conglomerates for which information on farmers is available and not only those close to the weather stations. There are other sources of interpolated data such as University of East Anglia Climatic Research Unit, Harris and Jones (2019) and Karger *et al.*, (2017), but their resolution level is lower (more degrees), so the variance in weather data is lower when working with small geographic units (such as the clusters of this work), so it is difficult to obtain accurate results.

## 5.2 ENA final sample

In this paper, not all the observations collected in the ENA are used. Three restrictions are used to exclude some observations. First, producers not engaged in an agrarian[13] activity (producers engaged solely in livestock activity) are excluded. In the second cut, producers for whom no information on the relevant variables is available are excluded. Finally, in the third cut, producers with outliers values in their revenue or expenditure are excluded.

The first cut is made because the paper focuses only on the dynamics of agrarian and not livestock (farmers who carry out both agricultural and livestock activities at the same time are not excluded). This is due to the fact that, in many cases, livestock dynamics differ from agrarian dynamics in the use of communal lands. Because there is no information about these lands, it is not possible to model the activity as it is done with the agrarian activity.

It also excludes producers for whom no weather information is available for analysis. This is because the weather data does not include some conglomerates located to the east of the country. Of the 19,096 conglomerates in the survey there is no information on 37. In this sense, it is necessary to exclude farmers located in these conglomerates since they cannot be joined to the weather base, and therefore their information cannot be used to estimate the relationship between weather and net agrarian revenue.

Finally, farmers with extreme values in net agrarian revenue variable are excluded. This is because, as will be seen in chapter 5.3, the net agrarian revenue variable is constructed with self-reported values, and by adding the quantities and prices of each of the crops and inputs. In this sense, it is possible that problems with the units of measurement might generate extreme values. In order to avoid subjectivities with which values to include and which to exclude, the procedure is done using the Modified Z-scores method proposed by Iglewicz and Hoaglin (1993) to detect outliers in the income and expenditure per hectare.[14] It is important to emphasize that the results are robust to the inclusion of these values, as will be seen in chapter 7. This technique is only applied in this variable because most of the control variables are dichotomous. The other variable on which a similar procedure could be performed is the size of the farms. However, as already mentioned, this variable was collected using a GPS to avoid measurement errors.

Table 5-1 shows the final number of observations that will be used in the paper

**Table 5-1: Final sample of farmers**

| | 2015 | 2016 | 2017 | Total |
|---|---|---|---|---|
| **Total ENA** | | | | |
| Sample | 27,788 | 28,164 | 28,177 | 84,129 |
| Weighted Sample | 2,244,679 | 2,244,674 | 2,244,679 | 6,734,032 |
| **Condition 1: Farmers engaged in agrarian activities** | | | | |
| Sample | 24,584 | 25,579 | 25,406 | 75,569 |
| Weighted Sample | 2,012,259 | 2,065,859 | 2,043,692 | 6,121,810 |
| % of total ENA (Weighted Sample) | 90% | 92% | 91% | 91% |
| **Condition 2: With information on weather variables/ Final sample** | | | | |
| Sample | 24,281 | 25,266 | 25,018 | 74,565 |
| Weighted Sample | 1,993,756 | 2,046,790 | 2,019,872 | 6,060,418 |
| % of total ENA (Weighted Sample) | 89% | 91% | 90% | 90% |
| **Condition 3: No outliers in net agricultural revenues** | | | | |
| Sample | 21,981 | 23,584 | 23,013 | 68,578 |
| Weighted Sample | 1,845,914 | 1,934,077 | 1,881,550 | 5,661,541 |
| % of total ENA (Weighted Sample) | 82% | 86% | 84% | 84% |

Source: Author's elaborations based on ENA 2015-2017

As can be seen, the most considerable reduction occurs after applying the first cut. After doing this, the weighted sample is reduced by 9%, so the population is reduced to 91%. The second cut reduces the weighted sample by only 1% of the total, and the population is reduced to 90%. Finally, the third cut reduces the sample by 6% of the total, and it is reduced to 84% of the total ENA. It is important to note that this is the population on which inference will be made, and therefore the conclusions drawn from this work are valid only for this sub-group of the population.[15]

## 5.3 Net agrarian revenue

As mentioned above, the objective of the work is to measure the effect of weather shocks on the net agrarian income of small and medium farmers. In this sense, the construction of the net agrarian revenue variable is crucial in this work. The construction of this variable was done through four stages:

1. Construction of total annual agrarian income
2. Construction of total annual agrarian expenditure
3. Construction of total annual net agrarian revenue
4. Temporal deflation of total annual net agrarian revenue

The construction of total annual agrarian income was done by adding the value of agrarian income from sales (price multiplied by the quantity of each of the crops destined for sale) and value of self-consumption (price multiplied by quantity of each of the crops destined for self-consumption), as shown in the following formula:

**Equation 5-1: Annual agrarian income**

$$IA_i = \sum_{b=1}^{n} Q_{vbi}P_{vbi} + \sum_{b=1}^{n} Q_{abi}P_{abi}$$

Where $\boldsymbol{IA}$ the annual agrarian income of the farmer $\boldsymbol{i}$ , $\boldsymbol{Q_v}$ is the quantity sold of the crop $\boldsymbol{b}$ (measured in kilos), $\boldsymbol{P_v}$ is the selling price of crop $\boldsymbol{b}$ (measured in soles (S/.) per kilos), $\boldsymbol{Q_a}$ is the quantity destined for self-consumption of the crop $\boldsymbol{b}$ (measured in kilos) and $\boldsymbol{P_a}$ is the destined for self-consumption price of crop $\boldsymbol{b}$ (measured in soles (S/.) per kilograms).

It is important to highlight three aspects of the previous equation; on one side it is considered as part of the agrarian income the self-consumption of the producers. This is because this component is vital to measure the welfare of producers (84% of the producers in the sample consume what they produce, so not including this component will not allow the capture of the entire production of the plot). On the other hand, the price of crops varies per farmer (it is not a fixed price per crop, that is why the prices depend on $\boldsymbol{i}$), as each producer reports the price at which he sold his crop. Finally, the component $\boldsymbol{P_a}$ is a reference price, since farmers are asked to value their own consumption per product in monetary units.

The construction of total annual agrarian expenditure follows a similar procedure. Thus, if this value is estimated by adding the values of the inputs used (measured in units), multiplied by the unit price of the input, as shown in the following formula:

**Equation 5-2: Annual agrarian expenditure**

$$IE = \sum_{i=1}^{n} Q_{ai} P_{ai}$$

Where $\boldsymbol{IE}$ the annual agrarian expenditure of the farmer, $\boldsymbol{Q}$ is the quantity used of the input $\boldsymbol{a}$[16] , and $\boldsymbol{P}$ is the destined for self-consumption price of crop $\boldsymbol{a}$ (measured in soles (S/.) per kilos). Same as with farm incomes, farm expenditure prices vary by producer.

The construction of annual net agrarian revenue is estimated by subtracting annual agrarian expenditure from annual agrarian income ($\boldsymbol{IA_i - IE_i}$). Since no restrictions are put in place, some producers have negative annual net agrarian revenue. In the entire sample, 19% of producers have a negative value. The producers with negative values are concentrated mainly in the Highlands, where 25% have a negative net agrarian revenue, compared to 7% in the Coast and 5% in the Rainforest.

Finally, because the information we have comes from different years, the values were deflated in time, in order to have constant 2015 soles as the monetary unit. This was done by dividing the value of each year by the cumulative inflation between 2015 and the year of the value being converted. [17] Since revenue depends on size, the annual net revenue was divided by the total number of hectares harvested in the year.

Table 5-2 shows the mean of the annual agrarian revenue (as well as the income and expenses):

**Table 5-2: Farmers income and expenses per region**

| | Coast | Highlands | Rainforest | Total pool (2015-2017) | Pvalue 1 | Pvalue 2 | Pvalue 3 |
|---|---|---|---|---|---|---|---|
| Observations | | | | | | | |
| Sample | 11,149 | 41,599 | 15,830 | 68,578 | | | |
| Expanded Sample | 610,821 | 3,861,791 | 1,188,929 | 5,661,541 | | | |
| Income and expenditure | | | | | | | |
| Total annual agrarian income (S./ 2015) | 20,703 | 2,504 | 10,672 | 6,183 | 0.000 | 0.000 | 0.000 |
| Total annual agrarian income per ha. Harvest (S./ 2015) | 6,976 | 3,190 | 3,962 | 3,761 | 0.000 | 0.000 | 0.000 |
| Total annual agrarian expenses (S./ 2015) | 4,894 | 778 | 2,184 | 1,517 | 0.000 | 0.000 | 0.000 |
| Total annual agrarian expenses per ha. Harvest (S./ 2015) | 1,771 | 1,258 | 737 | 1,204 | 0.000 | 0.000 | 0.000 |
| Total annual net agrarian revenue per ha. Harvest (S./ 2015) | 5,205 | 1,932 | 3,226 | 2,557 | 0.000 | 0.000 | 0.000 |

Pvalue1: Difference between Coast and Highlands, pvalue2: Difference between Coast and Rainforest, pvalue3: Difference between Highlands and Rainforest. All p values estimated using standard error grouped at the conglomerate level. Unit of monetary variables: Constant 2015 soles (S./). Source: Author's elaborations based on ENA2015-2017.

The above table shows that differences across regions are pronounced (and statistically significant) in terms of agrarian income and expenditure. The Coast is the region with the highest value in all these variables. Despite its relatively large agrarian expenditure (in comparison to other regions), its high agrarian income makes its annual net agrarian revenue per hectare harvested the highest, with a value of S./ 5,025, which is equivalent to $ 1,642.[18]

The Rainforest region is the second region with the highest net agrarian revenue per harvested hectare. Although it has a high agrarian expenditure, after standardizing these values regarding the harvested hectares, it is observed that the expenditure is lower than in the Highlands. The annual net agrarian revenue per harvested hectare of the Rainforest is S./ 3,226, which is equivalent to $ 1,054. The Highland is the region with the lowest values. The annual net agrarian revenue per harvested hectare in this region is S./ 1,932, which is equivalent to $ 631.

It is important to note that as can be seen in Appendix 5, even after eliminating the extreme values using the Modified Z-scores, the variable has a skewed distribution, which justifies its transformation before using it in the regression model (as mentioned in chapter 6).

To put these values into context, they can be compared against the poverty line[19]. Even though in Peru the poverty line is measured with expenditures, and the dependent variable of this paper is revenue, the comparison seems relevant to place producers within the national income distribution. This work requires transforming the variable from annual to monthly and from total household to per capita, since the poverty line is measured in those terms. As can be seen in table 5-3, net agrarian revenue lies below the poverty line in the Rainforest and the Highlands. Even for the Coast, whose average is above the poverty line, 67% of the farmers in the sample are below the poverty line.

**Table 5-3: Farmers net agrarian revenue and poverty line**

| | Coast | Highlands | Rainforest |
|---|---|---|---|
| Annual net agrarian revenue per ha. Harvest (S./ 2015) | 5,205 | 1,932 | 3,226 |
| Annual net agrarian revenue (S./ 2015) | 15,809 | 1,727 | 8,489 |
| Monthly net agrarian revenue (S./ 2015) | 1,317 | 144 | 707 |
| Net monthly net agrarian revenue per member (S./ 2015) | 521 | 50 | 243 |
| Poverty line (monthly per member) approx. | 302 | 250 | 260 |
| Households below the poverty line (only considering the net agrarian revenue) | 67% | 96% | 76% |

Unit of monetary variables: Constant 2015 soles (S./). Source: Author's elaborations based on ENA 2015-2017.

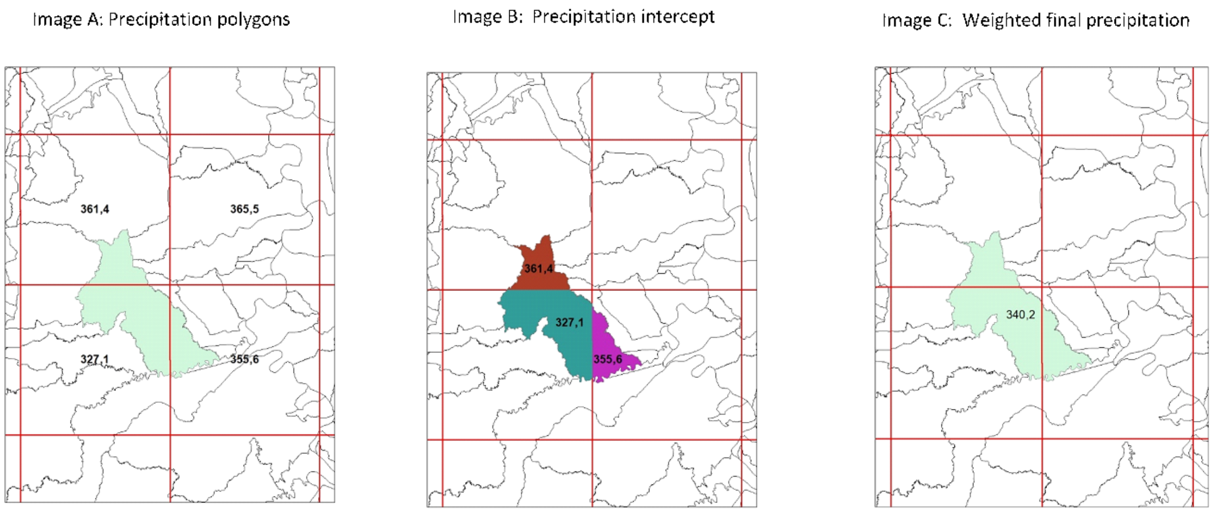
## 5.4 Weather variables

The construction of weather variables can be divided into two stages. The first stage is the linking the information to the conglomerates, and the second is the precise estimation of the statistics to be used in the paper.

As commented above, the Matsuura and Willmott (2018) base contain monthly temperature and rainfall information presented through a grid of approximately 28 square kilometers. Since the shapefile[20] of the ENA conglomerates is available, it is possible to overlap the grid to the conglomerates. Thus, each conglomerate is assigned the value of the grid that is in the same location (thus, all producers in a conglomerate have the same value for weather variables). This process is done for the two weather variables (temperature and rainfall) per month.

As expected, some conglomerates are contained within a grid, so the value of that grid is assigned to it. However, other conglomerates do not fit into a grid, so they are assigned the weighted average of the grids it intercepts. Figure 5-1 shows an example of this process using the January precipitation of 2017. As can be seen in image A, three temperature polygons fall on conglomerate 06158, each with different precipitation. As is shown in image B, the conglomerate was divided into three sub-conglomerates according to the three polygons; and each chapter was assigned the corresponding value. Finally, the original conglomerate was reconstructed, assigning as a value the weighted average according to the area of the subchapters.[21]

**Figure 5-1: Example of intercepting precipitation data with conglomerates (conglomerate 06158)**




Source: Author's elaborations based on Matsuura and Willmott (2018)

The definition of the statistic to be used in the model is based on the conceptual definition of weather variation. The literature usually defines climate as the average of the weather variables in a period of 30 years (Auffhammer *et al.*, 2011; Hsiang, 2016). That is, climate is a distribution, while weather is a point or a realization. Therefore, it is possible to define a weather shock as a variation of the weather variables (temperature and precipitations in this paper) over the 30-year mean (Dell, Jones and Olken, 2014).

Before estimating this variation, it is necessary to add monthly to annual weather information so that it is comparable with the ENA base. For this, it was decided to consider the temporality of the ENA in the collection of information. Because the ENA is conducted during the months of June-August but enquires about production in the last 12 months, it makes sense that the weather variables also have the same seasonality. Thus, the annual average of the weather variable was defined as the average of the weather variable for September from one year to August of the following year (for example, the average temperature of the year 2015 is the average temperature between September 2014 and August 2015).

Once the value per year has been defined, the average, as well as the standard deviation of the last 30 years (September 1986 to August 2017), was estimated. With these two parameters, the standard deviation per year was estimated.[22] This is the value that is used in the regression. Table 5-4 shows the descriptive statistics of these weather variables per year for the conglomerates in the sample.

**Table 5-4: Summary Statistics – Weather by year**

| Variable | 2015 | 2016 | 2017 | Pooled average |
|---|---|---|---|---|
| Average monthly precipitation (30 years distribution) (mm) | 73.30 | 72.78 | 73.73 | 73.27 |
| Average monthly precipitation of last 12 months (mm) | 81.08 | 68.25 | 87.17 | 78.81 |
| Standard deviation precipitation | 0.59 | -0.39 | 1.23 | 0.47 |
| Average monthly temperature (30 years distribution) (C) | 14.97 | 14.96 | 14.93 | 14.95 |
| Average monthly temperature of last 12 months (C) | 15.37 | 15.94 | 15.45 | 15.59 |
| Standard deviation temperature | 0.63 | 1.80 | 0.91 | 1.12 |
| Conglomerates | 2,014 | 2,032 | 2,021 | 6,067 |

Source: Author's elaborations based on Matsuura and Willmott (2018)

The precipitation and average temperature of the last 30 years (1986-2017) is a variable that is constructed based on the conglomerates present in the survey each year. Since the conglomerates in the survey differ per year, the average of the last 30 years also differs. It can be observed that in 2015 and 2017, the average precipitation was above the mean of the historical distribution, while in 2016 it was below. The significant divergence of 2017 with respect to the historical average is justified by the presence of the ENSO phenomenon in the first months of that year. Regarding the temperature, it can be observed that in the three years it was above the historical average. In 2016, the temperature was higher than the average by almost one degree Celsius.

Table 5-5 shows the same variables but divided according to region.

**Table 5-5: Summary Statistics – Weather by region**

| Variable | Coast | Highlands | Rainforest | Pooled average |
|---|---|---|---|---|
| Average monthly precipitation (30 years distribution) (mm) | 21.415 | 60.089 | 155.259 | 73.27 |
| Average monthly precipitation of the last 12 months (mm) | 27.366 | 67.269 | 155.93 | 78.81 |
| Standard deviation precipitation | 0.629 | 0.564 | 0.09 | 0.474 |
| Average monthly temperature (30 years distribution) (C) | 19.554 | 10.261 | 23.787 | 14.952 |
| Average monthly temperature of the last 12 months (C) | 20.422 | 10.857 | 24.321 | 15.586 |
| Standard deviation temperature | 1.211 | 1.045 | 1.223 | 1.115 |
| Conglomerates | 1,156 | 3,601 | 1,310 | 6,067 |

Source: Author's elaborations based on Matsuura and Willmott (2018)

In the table above one can observe that on average in all regions, both precipitation and temperature have been above the average distribution for the last 30 years. About precipitation, it is observed that the difference is higher in the Coast, which is consistent with the presence of ENSO in this region, while the difference in the Rainforest is minimal. As far as temperature is concerned, the most considerable discrepancy is in the Coast (0.86 degrees Celsius) followed by the Highlands (0.59 degrees Celsius) and then the Rainforest (0.53 degrees Celsius). However, when the standard deviations are estimated, it is the Rainforest the region that shows the most considerable divergence. Appendix 6 shows the average temperature and precipitation per conglomerate.

As will be discussed in chapter 6, the regression will be based on the standard deviation, so the results of the seventh chapter should be understood in that unit of measure. In order to simplify its interpretation, table 5-6 shows how much a standard deviation is equivalent to both in millimeters and Celsius degrees for precipitation and temperature, respectively.

**Table 5-6: Equivalence standard deviation**

| | Coast | Highlands | Rainforest | Pooled average |
|---|---|---|---|---|
| Standard deviation precipitation (mm) | 9.46 | 12.73 | 7.46 | 11.69 |
| Standard deviation temperature (C) | 0.72 | 0.57 | 0.44 | 0.57 |

Source: Author's elaborations based on Matsuura and Willmott (2018)

It can be observed that in the case of precipitation, a standard deviation equals 11.69 mm, while in the case of temperature equals 0.57 degrees Celsius. It is the average of the pool, which should be considered when interpreting the results of the aggregates, while the values of each region (which vary according to the distribution by region) should be referred to when analyzing the heterogeneous effects.

## 5.5 Other farmers characteristics

As will be explained in chapter 6, other factors could affect the relationship between climatic shocks and net agricultural revenue per hectare. That is why it is necessary to include these variables in the estimate. Table 5-7 shows the descriptive statistics of the producers. The variables presented are the control variables in the literature (see chapter 6.2). As mentioned above, an additional objective of the paper is to estimate heterogeneous effects by natural region. Due to this, it was decided to present the descriptive statistics disaggregated by this characteristic.

**Table 5-7: Farmers control variable per region**

| | Coast | Highlands | Rainforest | Total pool (2015-2017) | Pvalue 1 | Pvalue 2 | Pvalue 3 |
|---|---|---|---|---|---|---|---|
| Observations | | | | | | | |
| Sample | 11,149 | 41,599 | 15,830 | 68,578 | | | |
| Expanded Sample | 610,821 | 3,861,791 | 1,188,929 | 5,661,541 | | | |
| Demographic and context | | | | | | | |
| Age household head | 56.65 | 53.12 | 47.26 | 52.27 | 0.000 | 0.000 | 0.000 |
| Years engaged in independent agricultural activity | 23.21 | 27.55 | 22.6 | 26.05 | 0.000 | 0.000 | 0.000 |
| Sex household head (1=male) | 0.77 | 0.68 | 0.81 | 0.71 | 0.000 | 0.000 | 0.000 |
| HH education - Primary school or less (1=yes) | 0.58 | 0.71 | 0.66 | 0.68 | 0.000 | 0.000 | 0.000 |
| HH language - Spanish (1=yes) | 0.95 | 0.44 | 0.74 | 0.56 | 0.000 | 0.000 | 0.000 |
| Household head is engaged in other activities outside the farm (1=yes) | 0.52 | 0.5 | 0.57 | 0.52 | 0.000 | 0.000 | 0.000 |
| Household size | 3.64 | 3.63 | 4.02 | 3.71 | 0.000 | 0.000 | 0.000 |
| Ratio Household members over 6 years working | 0.8 | 0.95 | 0.92 | 0.93 | 0.000 | 0.000 | 0.000 |
| Distance to district capital (hrs.) auto report | 0.57 | 1.62 | 2.95 | 1.79 | 0.000 | 0.000 | 0.000 |
| Agricultural unit | | | | | | | |
| Total area | 3.34 | 3.86 | 12.19 | 5.56 | 0.000 | 0.000 | 0.000 |
| Harvested area | 2.55 | 0.88 | 3.84 | 1.68 | 0.000 | 0.000 | 0.000 |
| Herfindahl Index crops | 0.75 | 0.57 | 0.67 | 0.61 | 0.000 | 0.000 | 0.000 |
| Total crops | 2.66 | 3.62 | 3.72 | 3.54 | 0.000 | 0.000 | 0.000 |
| Have Technical irrigation (1=yes) | 0.71 | 0.36 | 0.04 | 0.33 | 0.000 | 0.000 | 0.000 |
| Agricultural services and practices | | | | | | | |
| Farmer has received agriculture technical assistance (1=yes) | 0.04 | 0.02 | 0.1 | 0.04 | 0.000 | 0.000 | 0.000 |
| Farmer has received agriculture training (1=yes) | 0.06 | 0.04 | 0.14 | 0.07 | 0.000 | 0.000 | 0.000 |
| Obtain the credit (1=yes) | 0.25 | 0.08 | 0.14 | 0.11 | 0.000 | 0.000 | 0.000 |
| Have an insurance (not health or climate) (1=yes) | 0.01 | 0.01 | 0 | 0.01 | 0.000 | 0.000 | 0.000 |
| Belongs to an association, cooperative or farmers committee (1=yes) | 0.06 | 0.04 | 0.12 | 0.06 | 0.000 | 0.000 | 0.000 |
| Belongs to the irrigation association (1=yes) | 0.8 | 0.33 | 0.03 | 0.32 | 0.000 | 0.000 | 0.000 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Number of degradation practices 0-4 | 0.94 | 1.53 | 0.39 | 1.23 | 0.000 | 0.000 | 0.000 |
| Number of soil cultivation practices 0-4 | 2.2 | 2.49 | 0.5 | 2.04 | 0.000 | 0.000 | 0.000 |
| Number of water practices 0-4 | 1.85 | 0.64 | 0.09 | 0.65 | 0.000 | 0.000 | 0.000 |
| Number of agricultural inputs practices 0-5 | 2.14 | 1.81 | 1.06 | 1.69 | 0.000 | 0.000 | 0.000 |

Pvalue1: Difference between Coast and Highlands, pvalue2: Difference between Coast and Rainforest, pvalue3: Difference between Highlands and Rainforest. All p values estimated using standard error grouped at the conglomerate level. Source: Author's elaborations based on ENA 2015-2017.

Concerning demographic characteristics, there are clear differences between natural regions. The oldest producers are found on the Coast, followed by producers from the Highlands region and then from the Rainforest. It is interesting to note that years of experience in the agricultural activity do not follow this pattern, with Highlands producers having the most experience, indicating that they are engaged in agriculture from a younger age. In the Rainforest region there is a higher proportion of male producers than in other regions. In the Highlands region 71% of the producers have the highest level of primary education, and only 44% speak Spanish, this contrasts with the Coast where 95% speak Spanish. In the Rainforest, the producers dream of dedicating themselves more to other activities outside the property than in other regions. The Coast has the lowest ratio of domestic work and greater proximity to the district capitals.

As for the characteristics of the agricultural unit, it can be observed that the Rainforest producers have larger farms (this is due to the presence of mountains and forests). Although they also have a larger harvested area, if the ratio of harvested area to total area is estimated, it can be concluded that the Coast make more productive use of the land. The Rainforest is also the region with the most considerable diversification, measured as the Herfindahl Index of crops or the total number of crops. Finally, the coastal producers make more use of technical irrigation, while only 4% of the Rainforest producers make use of this type of irrigation (which may correspond to the high level of precipitations in that region, as can be seen in table 5.5).

The Rainforest region has the most significant access to technical assistance and training. However, in terms of credit, the Coast producers have the greatest access. In the three regions, there is practically no access to insurance. There is a higher membership of associations in the Rainforest, which is consistent with the model of cooperatives present in the production of cocoa and coffee in this area. Membership of irrigation associations is mandatory in most of the Coast valleys, so its high percentage compared to other regions is not surprising. Finally, it can be observed that the Rainforest producers perform fewer agricultural practices than the rest of the producers. Besides, the producers of the Highlands are those who perform a more significant number of practices to prevent soil degradation and use, while the producers of the Coast perform a higher number of practices in what corresponds to water and use of inputs.

# Chapter 6
# Methodology

This chapter presents the methodology to be used to estimate the effect of climatic shocks on agrarian revenues. The first subchapter presents the econometric model that will be estimated. Also, that subchapter elaborates on the manner in which the independent variable is treated, as well as on the estimation of standard errors. The second subchapter presents the literature that justifies the choice of control variables.

## 6.1 Model

The literature suggests that the most appropriate model for estimating the relationship between net farm revenue and weather fluctuations should be based on panel data and a fixed-effect model may be estimated at the producer level. This type of model makes it possible to know the revenue of the same farmer during different weather events. This is because since it is the same producer in different periods, variations in revenue may be attributed to the weather (Dell, Jones and Olken, 2014).

Unfortunately, at the moment, there is no panel data on farm producers in Peru. Thus, this paper relies on pooling data from three cross-section surveys of producers conducted in 2015, 2016 and 2017 and estimates a fixed-effect model at the level of geographical units. To elaborate, although we do not have information from the same producer in different periods of time, we use information from the same geographical units in different periods of time. This approach exploits weather variations experienced by different small farmers in different years in the same geographical space

Analytically, the proposed relationship to be estimated is the following (Dell, Jones and Olken, 2014; Hsiang, 2016):

**Equation 6-1: Model specification**

$$\boldsymbol{y}_{ict} = \beta \boldsymbol{C}_{ct} + \gamma \boldsymbol{C}^2{}_{ct} + \alpha \boldsymbol{X}_{ict} + \boldsymbol{\varphi}_c + \boldsymbol{\theta}_t + \boldsymbol{\varepsilon}_{ict}$$

The subscripts $\boldsymbol{i}$, $\boldsymbol{c}$ $\boldsymbol{t}$ represent the smallholders, the conglomerate (geographical unit), and time respectively. While $\boldsymbol{y}$ is a transformation of net agrarian revenue per harvested hectare, $\boldsymbol{C}$ is a vector that contains the standard deviation of the weather variables (temperature and precipitations) with respect to their long-term trend (30 years, as mentioned in the chapter 6.4.), $\boldsymbol{X}$ is a vector that contains individual (household and farm) control variables (they will be presented in chapter 6.2), $\boldsymbol{\varphi}$ and $\boldsymbol{\theta}$ represents conglomerate and time fixed effects respectively, and $\boldsymbol{\varepsilon}$ is an error term. As can be seen, the weather variable vector is included twice, linearly and quadratically. This is done in line with the literature in order to capture potential non-linearities of the relationship.

There are three aspects worth discussing about the estimation. The first has to do with the transformation of the dependent variable. As mentioned in the previous paragraph $\boldsymbol{y}$ will not take the value of net revenue per hectare, but a transformation of this variable. This is because the variable has a skewed distribution (as mentioned in chapter 5.3). This can cause the regression residual not to be symmetrically distributed around 0. This is a necessary requirement for efficient estimates. Due to the above, it is proposed to use some transformation of the revenue per hectare harvested that allows normalizing this variable.

The most common transformation to reduce the skewness of a variable is the logarithmic transformation. Mendelsohn and Massetti (2017), claim that log linear models are more useful than a linear model in the context of agrarian effects. This is because these models estimate a proportional effect that seems to fit reality. Since in our case there are positive and negative values in net agrarian revenue per hectare (see chapter 5.3), it is not possible to use this transformation[23]. Because of this, it is proposed to use the inverse hyperbolic sine (IHS) transformation. The IHS is a mathematical function defined as:

**Equation 6-2: Inverse hyperbolic sine**

$$IHS = \ln\left(y + (y^2 + 1)^{\frac{1}{2}}\right)$$

Where $y$ is the variable to be transformed (net agrarian revenue per hectare). The main advantage of this transformation over the logarithmic transformation is that it allows maintaining negative values and zeros. (Burbidge, Magee and Robb, 1988; Bellemare, Barrett and Just, 2013; Friedline, Masa and Chowa, 2015). In order to be able to interpret the coefficients as semi-elasticity,[24] this paper adapts[25] the step suggested by Bellemare and Wichman (2019):

**Equation 6-3: Marginal effect weather (semi-elasticity)**

$$\varepsilon_{yc} = \left(\hat{B}\bar{C}\frac{\sqrt{\bar{y}^2+1}}{\bar{y}}\right) + 2\left(\hat{\gamma}\overline{C^2}\frac{\sqrt{\bar{y}^2+1}}{\bar{y}}\right)$$

Where $\boldsymbol{\varepsilon_{yc}}$ is the percentage change of the net agrarian revenue with respect to the weather variable (precipitations or temperature), $\hat{\boldsymbol{B}}$ and $\hat{\boldsymbol{\gamma}}$ are coefficients estimated by equation 5-1, $\bar{\boldsymbol{C}}$ is the mean of the weather variable, $\overline{\boldsymbol{C^2}}$ is the mean of the square weather variable, and $\bar{\boldsymbol{y}}$ and is the mean of the net agrarian revenue per hectare.

The second aspect that is worth discussing is what type of standard errors to estimate. It is proposed to cluster standard errors at the conglomerate level. There are two reasons for this. As mentioned in chapter 5.2, the primary data source has a two-stage sampling design, in which clusters are selected first and then producers. Under this type of design "clustering adjustment is justified by the fact that there are clusters in the population that we do not see in the sample" (Abadie *et al.*, 2017). Besides, conceptually, it makes sense that residuals are correlated at the conglomerate level (because they are exposed to them that are not observable). As MacKinnon (2019) mentions, the inclusion of fixed effects at the conglomerate level (as proposed in this paper) only corrects part but not all of the intra-cluster correlation, so it is necessary to cluster the standard errors in order to avoid that the standard errors are smaller than they should be.

Finally, the third aspect to pay attention to is the presence of variables at different levels. As it was show in the Chapter 5, the weather variables do not come from the same data source as the farmer variables. Due to this, they are aggregated at a higher level, i.e., they are constant within the conglomerate. Using independent variables added at different levels in an ordinary least squares model can cause standard errors to be biased. However, since a fixed-effects model is used at the conglomerate level, each conglomerate is allowed to have its own intercept, removing the bias in standard errors (Moulton 1986).

As it has been mentioned, the sub-objective of the paper is to know if there are differences in the effects according to the natural region in which the producers are located. The traditional way to detect heterogeneous effects is to include in the model the categorical variable of the groups to be evaluated (in our case, the natural regions) and their interaction with the variable of relevance (in our case, the climatic variables). In our case, this is not possible since all producers within a conglomerate are located within the same natural region. Due to this, heterogeneous effects are estimated by dividing the sample according to natural regions and estimating equation 6-1 model for each sub-sample.

## 6.2 Control variables

The inclusion of the specific control variables responds to both, the ability of the data in the ENA, and to theory. In that sense, the selection of the variables is primarily based on the study of Escobal and Armas (2015) who develop a conceptual model that links the characteristics of agricultural units and their environment, which generates specific productive strategies and specific results, in the context of Peru.

The first types of characteristic of the producers are their demographic characteristics. The first variable is the age of the head of household. A non-linear relationship is expected for this variable because as age increases, income should increase due to experience. However, at a certain point, income may decrease due to the potentially debilitating effects of age. (Lazzaroni, 2012). In this sense, age and square age are included to model this non-linearity. Also, due to data availability, experience and experience squared are included.

Another demographic variable included is the sex of the head of the household. As the study of Zegarra (2019) shows, in recent years, the presence of female heads of the household has increased in rural Peru. However, access to services continues to stay deficient for them, making it an important variable in terms of production. The education and language of the head of the household are also included. These variables may have a significant effect on the productivity of Peruvian farmers as they potentially affect their access to information and services (Espinoza *et al.*, 2018). These categorical variables are transformed into dichotomous variables as some categories have very low percentages. Thus, the education variable is transformed into a variable that indicates whether the producer has not completed the primary level of education, and the language variable into a variable that indicates whether the producer has Spanish as his language. Appendix 4 shows the distribution of each of the categories.

In addition to the size of the household, the percentage of members of the household who work in agricultural activities, and whether the head of household engages in other economic activities outside the premises are additional demographic variables. The first two directly measure the labor force available to and used by the family. Thus, these variables are expected to increase productivity and therefore income. On the other hand, engaging in other economic activities can be understood as a decrease in the labor force, so for this variable the opposite effect is expected. The latter is also treated in literature as an income diversification strategy (Barrett, Reardon and Webb, 2001).

The second types of characteristics of the producers are the characteristics of the agricultural unit. The two characteristics that are included in this dimension are the area of the land and crop diversification. There is contradictory evidence on the positive or negative relationship between land size and productivity (and income). A summary of this evidence is in Eastwood, Lipton and Newell (2010). Regardless of the expected sign, it is clear that it is essential to include this variable in the Ricardian model, as suggested by Mendelsohn, Nordhaus and Shaw (1994).

Crop diversification is measured by the Herfindal Index of Crops. This is one of several measurements suggested by Pal and Kar (2012), to capture crop diversification.[26] The index takes values between 0 and 1, and an increase in the index indicates less diversification. The main advantage of the index over a crop count is that it considers the area dedicated to each crop. There is evidence that greater crop diversification increases producers' incomes, as suggested by Pellegrini and Tasciotti (2014).

The third type of characteristics of producers are those related to their access to agricultural services and practices. The first variables to be included in this category are access to technical assistance and training.[27] There is empirical evidence that these variables positively influence agricultural yield and income (Davis *et al.*, 2012). In the Peruvian case, several studies show that farmers perceive the existence of these services positively, for example Ruben and Fort (2012).

Also, as variables of access to services are included access to credit and the possession of insurance. These variables are present in various studies using the Ricardian model, such as Huong, Bo and Fahad (2018) and Hossain *et al.* (2019). Regarding agricultural practices, the methodology of Tambet (2018) is followed to generate four variables of good agricultural practices, practices that avoid soil degradation, soil cultivation practices, water management practices, and input use practices. Each variable indicates the number of practices carried out in each category.

Concerning contextual variables, the self-reported distance to the district capital, measured in hours, is included. This variable is a proxy for the transaction costs of producers, so it should directly affect the income of producers (Escobal and Cavero, 2012). Due to the inclusion of conglomerate fixed effects, it is not necessary to include other contextual variables as a natural region, since there is no variation at that level.

# Chapter 7
# Results

In this chapter, we present the results of the model described in chapter 6.1. The chapter is divided into two subchapters. The first part contains the results for the entire sample in order to answer the research question. In the second subchapter, the results are presented dividing the sample by regions in order to answer the research sub-question about the possible heterogeneous effects by natural region.

## 7.1 National results

Before showing the results using the IHS transformation of net agrarian revenue, table 7-1 shows a summary of the results using the non-transform dependent variable. In order to examine the sensitivity of the results to the different control variables, they were added progressively and in groups according to the type of variables. Full results are presented in Appendix 7.

**Table 7-1: Summary of national results using the non-transform net agrarian revenue**

| | Value | Standard Error |
|---|---|---|
| Model 1: No control | | |
| Coefficient Precipitation | -44.286 | (50.87) |
| Coefficient Temperature | -211.665* | (117.11) |
| Coefficient Precipitation square | -12.851 | (16.41) |
| Coefficient Temperature square | -34.065 | (39.31) |
| Marginal effect Precipitation | -55.702 | (42.77) |
| Marginal effect Temperature | -285.841*** | (80.55) |
| | | |
| Model 2: Demographic controls | | |
| Coefficient Precipitation | -46.054 | (50.74) |
| Coefficient Temperature | -200.861* | (116.73) |
| Coefficient Precipitation square | -13.027 | (16.37) |
| Coefficient Temperature square | -36.587 | (39.30) |
| Marginal effect Precipitation | -57.626 | (42.65) |
| Marginal effect Temperature | -280.527*** | (80.38) |
| | | |
| Model 3: Demographic controls+ Farm controls | | |
| Coefficient Precipitation | -36.701 | (50.94) |
| Coefficient Temperature | -213.815* | (118.09) |
| Coefficient Precipitation square | -16.172 | (16.49) |
| Coefficient Temperature square | -36.224 | (39.47) |
| Marginal effect Precipitation | -51.068 | (42.78) |
| Marginal effect Temperature | -292.691*** | (80.84) |
| | | |
| Model 4: Demographic controls+ Farm controls+ Services control | | |
| Coefficient Precipitation | -37.456 | (50.97) |
| Coefficient Temperature | -216.391* | (118.08) |
| Coefficient Precipitation square | -15.971 | (16.49) |
| Coefficient Temperature square | -36.063 | (39.51) |
| Marginal effect Precipitation | -51.644 | (42.80) |
| Marginal effect Temperature | -294.916*** | (80.88) |
| | | |

| Model 5: Demographic controls+ Farm controls+ Services control+ Practices control | | |
|---|---|---|
| Coefficient Precipitation | -43.214 | (51.61) |
| Coefficient Temperature | -189.540 | (117.59) |
| Coefficient Precipitation square | -14.373 | (16.63) |
| Coefficient Temperature square | -40.250 | (39.50) |
| Marginal effect Precipitation | -55.982 | (43.28) |
| Marginal effect Temperature | -277.182*** | (81.28) |

Source: Author's elaborations. Dependent variable: net agrarian revenue per ha harvested. The number of observations in all estimations is 68,578. All estimations include conglomerate and time fixed effects. Standard error grouped at the conglomerate level in parentheses. Sig: * 0.1, ** 0.5, *** 0.01.

It is observed that in models 1 to 4 only the coefficient associated with the linear term of temperature has a statistically significant effect, while in model 5 no coefficient is statistically significant. Since client variables have been included twice in the model (linear and quadratic), it is necessary to estimate the overall effect of the variable. Marginal effects capture this effect. It is observed that in all models the marginal effect of temperature is negative and statistically significant. The magnitude of the effect is between -277 and -294 depending on the model. In the case of precipitation, the magnitude of the effect is between -51 and -57; however, this is not statistically significant. Since the literature demonstrates that farm characteristics have a relevant impact on productivity, the work takes as its primary specification the most complete specification (model 5).

In the models estimated in table 7-1 the dependent variable is net agrarian revenue per ha harvested. Therefore, from the last specification, it may be concluded that an increase of 1 standard deviation of the temperature translates into a decrease in the net agrarian revenue per ha harvested of S./ 277. In order to put these results in context, it is necessary to refer to the average value of a standard deviation in the temperature presented in table 5-7. In that sense, it is possible to affirm that increase of 0.57 degrees Celsius reduces the net agrarian revenue per ha harvested by S./ 277 (or 10% of net agrarian revenue per ha harvested according to the average presented in table 5-2)

As mentioned in chapter 6.1, the variable, the variable net agrarian revenue per ha harvested has a skewed distribution. That is why it is proposed to estimate the IHS transformation of the variable and estimate the model suggested in equation 6-1. Table 7-2 shows a summary of the results. The full results are presented in Appendix 8.

**Table 7-2: Summary of national results using the IHS transformation of the net agrarian revenue**

| | Value | Standard Error |
|---|---|---|
| Model 1: No control | | |
| Coefficient Precipitation | -0.141 | (0.10) |
| Coefficient Temperature | -0.016 | (0.18) |
| Coefficient Precipitation square | -0.000 | (0.03) |
| Coefficient Temperature square | -0.110* | (0.06) |
| Marginal effect Precipitation | -0.026 | (0.02) |
| Marginal effect Temperature | -0.048** | (0.02) |
| | | |
| Model 2: Demographic controls | | |
| Coefficient Precipitation | -0.140 | (0.10) |
| Coefficient Temperature | -0.019 | (0.18) |
| Coefficient Precipitation square | -0.001 | (0.03) |
| Coefficient Temperature square | -0.110* | (0.06) |
| Marginal effect Precipitation | -0.026 | (0.02) |
| Marginal effect Temperature | -0.048** | (0.02) |

| | | |
|---|---|---|
| | | |
| Model 3: Demographic controls+ Farm controls | | |
| Coefficient Precipitation | -0.089 | (0.10) |
| Coefficient Temperature | -0.112 | (0.19) |
| Coefficient Precipitation square | -0.017 | (0.03) |
| Coefficient Temperature square | -0.107* | (0.06) |
| Marginal effect Precipitation | -0.021 | (0.02) |
| Marginal effect Temperature | -0.068*** | (0.03) |
| | | |
| Model 4: Demographic controls+ Farm controls+ Services control | | |
| Coefficient Precipitation | -0.090 | (0.10) |
| Coefficient Temperature | -0.113 | (0.19) |
| Coefficient Precipitation square | -0.016 | (0.03) |
| Coefficient Temperature square | -0.110* | (0.06) |
| Marginal effect Precipitation | -0.020 | (0.14) |
| Marginal effect Temperature | -0.067 | (0.33) |
| | | |
| Model 5: Demographic controls+ Farm controls+ Services control+ Practices control | | |
| Coefficient Precipitation | -0.093 | (0.10) |
| Coefficient Temperature | -0.097 | (0.19) |
| Coefficient Precipitation square | -0.016 | (0.03) |
| Coefficient Temperature square | -0.112* | (0.06) |
| Marginal effect Precipitation | -0.021 | (0.02) |
| Marginal effect Temperature | -0.067** | (0.03) |

Source: Author's elaborations. Dependent variable: IHS transformation of the net agrarian revenue per ha harvested. The number of observations in all estimations is 68,578. All estimations include conglomerate and time fixed effects. Standard error grouped at the conglomerate level in parentheses. Sig: * 0.1, ** 0.5, *** 0.01.

As in the model without transforming the net agrarian revenue, this model shows that temperature has a negative and significant effect on the net agrarian revenue, while precipitation has a negative effect but not statistically significant. As mentioned above, in this case the coefficients can be understood as a percentage point change in net agrarian revenue per hectare, due to a one standard deviation increase in the weather variables (semi elasticity). Therefore, from the last specification, it may be concluded that an increase of 1 standard deviation (of the long term-30 year- mean) of the temperature (0.57 C) have and impact of 6.7 percentage point decrease in net agricultural revenue per hectare harvested. Thus, it is possible to affirm that an increase in 0.57 C on the average temperature in the last 30 years in Peru, will reduce the net agrarian revenue per hectare by S./ 171 (according to the average presented in table 5-2)

As mentioned in chapter 5.2, the final sample excludes observations that had outlies values in both income and agrarian expenditure per hectare. In order to know if the results vary due to this restriction, appendix 9 shows the results of the model including these observations. It can be seen that the direction of the effects is the same. The semi elasticity of the standard deviation of temperature is 9.5 percentage points in the primary specification. Therefore, when outliers observations are included the effect of an increase in 0.57 C on the average temperature in the last 30 years in Peru reduces the net agrarian revenue per hectare by S./ 243.

In all estimate's deviation in the temperature has a negative effect on farm revenue. This is consistent with the study of Seo, Mendelsohn and Munasinghe (2005), who claim that unlike the USA, in tropical and semi-tropical areas changes in weather could have negative effects on agricultural production. The estimated effects on this paper are similar to those estimated by Seo and Mendelsohn (2007) for small farms in Latin America (6.7 and 7 percentage points respectively).

## 7.2 Regional results

As we have seen in both chapters 2 and chapter 5, there is heterogeneity between the agrarian dynamics of producers according to the natural region in which they are located. Due to the above, it is expected that the existence of differentiated effects according to these regions. As discussed in chapter 6.1, this is done by dividing the sample into sub-samples according to the natural region and estimating the model of equation 6-1 for each of them. Table 7-3 shows the summary of the results for the Coast region. The full results are presented in Appendix 10.

**Table 7-3: Summary of Coast results**

| | Value | Standard Error |
|---|---|---|
| Model 1: No control | | |
| Coefficient Precipitation | -0.080 | (0.17) |
| Coefficient Temperature | -0.421 | (0.44) |
| Coefficient Precipitation square | -0.001 | (0.04) |
| Coefficient Temperature square | -0.127 | (0.14) |
| Marginal effect Precipitation | -0.010 | (0.02) |
| Marginal effect Temperature | -0.093*** | (0.03) |
| | | |
| Model 2: Demographic controls | | |
| Coefficient Precipitation | -0.035 | (0.17) |
| Coefficient Temperature | -0.519 | (0.43) |
| Coefficient Precipitation square | -0.007 | (0.04) |
| Coefficient Temperature square | -0.108 | (0.13) |
| Marginal effect Precipitation | -0.006 | (0.02) |
| Marginal effect Temperature | -0.100*** | (0.03) |
| | | |
| Model 3: Demographic controls+ Farm controls | | |
| Coefficient Precipitation | -0.004 | (0.17) |
| Coefficient Temperature | -0.548 | (0.42) |
| Coefficient Precipitation square | -0.006 | (0.04) |
| Coefficient Temperature square | -0.114 | (0.13) |
| Marginal effect Precipitation | -0.002 | (0.02) |
| Marginal effect Temperature | -0.107*** | (0.03) |
| | | |
| Model 4: Demographic controls+ Farm controls+ Services control | | |
| Coefficient Precipitation | -0.006 | (0.17) |
| Coefficient Temperature | -0.555 | (0.42) |
| Coefficient Precipitation square | -0.006 | (0.04) |
| Coefficient Temperature square | -0.113 | (0.13) |
| Marginal effect Precipitation | -0.002 | (0.02) |
| Marginal effect Temperature | -0.107*** | (0.03) |
| | | |
| Model 5: Demographic controls+ Farm controls+ Services control+ Practices control | | |
| Coefficient Precipitation | -0.029 | (0.17) |
| Coefficient Temperature | -0.367 | (0.43) |
| Coefficient Precipitation square | 0.001 | (0.04) |
| Coefficient Temperature square | -0.162 | (0.13) |
| Marginal effect Precipitation | -0.003 | (0.02) |

| | | |
|---|---|---|
| Marginal effect Temperature | -0.099*** | (0.03) |

Source: Author's elaborations. Dependent variable: IHS transformation of the net agrarian revenue per ha harvested. The number of observations in all estimations is 11,149. All estimations include conglomerate and time fixed effects. Standard error grouped at the conglomerate level in parentheses. Sig: * 0.1, ** 0.5, *** 0.01.

As in the case of the whole sample, all coefficients (and semi elasticity's) were negative. Also, the standard deviation of precipitation is not statistically significant. The effect of the increase in the standard deviation of the temperature is higher in this region compared to the national level. Thus, it is observed that the increase in an increase of 1 standard deviation (of the long term-30 year- mean) of the temperature decreases the net agrarian revenue per hectare harvested in 9.9 percentage points. Using the average revenue per hectare of this region, as well as the standard deviation of the temperature, can be translated as an increase in 0.72 C on the average temperature in the last 30 years in Peru, which will reduce the net agrarian revenue per hectare in S./ 515. Table 7-4 shows the summary of the results for the Highland region. The full results are presented in Appendix 11.

**Table 7-4: Summary of Highlands results**

| | Value | Standard Error |
|---|---|---|
| Model 1: No control | | |
| Coefficient Precipitation | -0.197 | (0.14) |
| Coefficient Temperature | 0.326 | (0.32) |
| Coefficient Precipitation square | -0.006 | (0.04) |
| Coefficient Temperature square | -0.147 | (0.10) |
| Marginal effect Precipitation | -0.048* | (0.03) |
| Marginal effect Temperature | 0.007 | (0.06) |
| | | |
| Model 2: Demographic controls | | |
| Coefficient Precipitation | -0.200 | (0.14) |
| Coefficient Temperature | 0.321 | (0.32) |
| Coefficient Precipitation square | -0.005 | (0.04) |
| Coefficient Temperature square | -0.143 | (0.10) |
| Marginal effect Precipitation | -0.049* | (0.03) |
| Marginal effect Temperature | 0.008 | (0.06) |
| | | |
| Model 3: Demographic controls+ Farm controls | | |
| Coefficient Precipitation | -0.143 | (0.14) |
| Coefficient Temperature | 0.355 | (0.32) |
| Coefficient Precipitation square | -0.031 | (0.04) |
| Coefficient Temperature square | -0.172* | (0.10) |
| Marginal effect Precipitation | -0.047 | (0.03) |
| Marginal effect Temperature | 0.002 | (0.07) |
| | | |
| Model 4: Demographic controls+ Farm controls+ Services control | | |
| Coefficient Precipitation | -0.144 | (0.14) |
| Coefficient Temperature | 0.362 | (0.32) |
| Coefficient Precipitation square | -0.028 | (0.04) |
| Coefficient Temperature square | -0.179* | (0.10) |
| Marginal effect Precipitation | -0.046 | (0.03) |
| Marginal effect Temperature | 0.000 | (0.07) |
| | | |
| Model 5: Demographic controls+ Farm controls+ Services control+ Practices control | | |
| Coefficient Precipitation | -0.142 | (0.14) |
| Coefficient Temperature | 0.293 | (0.33) |
| Coefficient Precipitation square | -0.030 | (0.04) |

| | | |
|---|---|---|
| Coefficient Temperature square | -0.158 | (0.10) |
| Marginal effect Precipitation | -0.047 | (0.03) |
| Marginal effect Temperature | -0.006 | (0.07) |

Source: Author's elaborations. Dependent variable: IHS transformation of the net agrarian revenue per ha harvested. The number of observations in all estimations is 41,599. All estimations include conglomerate and time fixed effects. Standard error grouped at the conglomerate level in parentheses. Sig: * 0.1, ** 0.5, *** 0.01.

The Highlands have different effects in comparison to the other regions. In this case, neither the standard deviation of the temperature or the precipitation has a statistically significant effect. In this region, the magnitude of semi-elasticity of precipitation is bigger (in absolute values) than the semi-elasticity of temperature, and it is significant in models 1 and 2, but not the last model. Finally, table 7-5 shows a summary of the results for the Rainforest region. Full results are presented in Appendix 12

**Table 7-5: Summary of Rainforest results**

| | Value | Standard Error |
|---|---|---|
| Model 1: No control | | |
| Coefficient Precipitation | -0.009 | (0.10) |
| Coefficient Temperature | -0.333* | (0.20) |
| Coefficient Precipitation square | 0.016 | (0.05) |
| Coefficient Temperature square | 0.044 | (0.06) |
| Marginal effect Precipitation | -0.000 | (0.01) |
| Marginal effect Temperature | -0.029 | (0.02) |
| | | |
| Model 2: Demographic controls | | |
| Coefficient Precipitation | -0.001 | (0.10) |
| Coefficient Temperature | -0.348* | (0.20) |
| Coefficient Precipitation square | 0.013 | (0.05) |
| Coefficient Temperature square | 0.040 | (0.07) |
| Marginal effect Precipitation | 0.001 | (0.01) |
| Marginal effect Temperature | -0.032* | (0.02) |
| | | |
| Model 3: Demographic controls+ Farm controls | | |
| Coefficient Precipitation | 0.040 | (0.10) |
| Coefficient Temperature | -0.485** | (0.21) |
| Coefficient Precipitation square | -0.003 | (0.05) |
| Coefficient Temperature square | 0.054 | (0.07) |
| Marginal effect Precipitation | 0.005 | (0.01) |
| Marginal effect Temperature | -0.045** | (0.02) |
| | | |
| Model 4: Demographic controls+ Farm controls+ Services control | | |
| Coefficient Precipitation | 0.039 | (0.10) |
| Coefficient Temperature | -0.480** | (0.21) |
| Coefficient Precipitation square | -0.003 | (0.05) |
| Coefficient Temperature square | 0.055 | (0.07) |
| Marginal effect Precipitation | 0.005 | (0.01) |
| Marginal effect Temperature | -0.044** | (0.02) |
| | | |
| Model 5: Demographic controls+ Farm controls+ Services control+ Practices control | | |
| Coefficient Precipitation | 0.024 | (0.10) |
| Coefficient Temperature | -0.424** | (0.21) |
| Coefficient Precipitation square | -0.007 | (0.05) |
| Coefficient Temperature square | 0.038 | (0.07) |
| Marginal effect Precipitation | 0.003 | (0.01) |

| | | |
|---|---|---|
| Marginal effect Temperature | -0.043** | (0.02) |

Source: Author's elaborations. Dependent variable: IHS transformation of the net agrarian revenue per ha harvested. The number of observations in all estimations is 15,830. All estimations include conglomerate and time fixed effects. Standard error grouped at the conglomerate level in parentheses. Sig: * 0.1, ** 0.5, *** 0.01.

The results in the Rainforest region are similar to those found on the Coast (and at the national level). In this region, the increase in the standard deviation of precipitation does not have a statistically significant effect, while the increase in the standard deviation of temperature does. Thus, it is observed that the increase in an increase of 1 standard deviation (of the long term-30 year- mean) of the temperature decreases the net agrarian revenue per hectare harvested in 4.3 percentage points. Using the average revenue per hectare of this region, as well as the standard deviation of the temperature, can be translated as an increase in 0.44 C on the average temperature in the last 30 years in Peru, will reduce the net agrarian revenue per hectare in S./ 139.

It has been observed that there are differences both in the magnitudes and in the significance of weather variables by natural regions. On the Coast the increase in temperature has a greater effect. This could be due to the ENSO phenomenon that occurs in this region in 2017. As already stated, the losses in the agricultural sector were of USD 700 million (Angulo, 2017). On the other hand, there are no negative effects of the temperature increase in the Highland. This is consistent with studies that state that there is less (or no effect) in cold areas. (Seo, Mendelsohn and Munasinghe, 2005; Mendelsohn and Reinsborough, 2007). In addition to the above factors, heterogeneous effects may also be due to crop diversity (table 2-4) because the weather has a different effect according to the crops (Carleton and Hsiang, 2016).

## 7.3 Projection

From the actual estimate in chapter 7.1 (table 7-2), it is possible to extrapolate the effects towards the end of the 21st century using the temperature projections of the IPCC (2014). The validity of these projections is based on the following assumptions:

1. The average temperature for the period 1986-2017 (reference range of this paper) is similar to the average temperature for the period 1986-2005 (IPCC reference temperature).
2. The relationship between temperature and agrarian revenue found in this paper follows the same relationship for temperature ranges other than those observed in this paper (No tipping points).
3. Farmers do not change their practices when faced with temperatures outside the range shown in this paper.
4. The temperature variation in Peru towards the end of the 21st century is equal to the average global temperature variation.

Since the assumptions are difficult to hold, the estimates in this subsection should only be taken as reference approximations. Table 7-6 shows the decrease in revenue according to the average temperatures of the 4 Representative Concentration Pathways (RCP).

**Table 7-6: Projection of impacts towards the end of the 21st century**

| Scenario | Mean temperature increases towards the end of the 21st century (above average 1985/2005) | Percentage point reduction | Reduction of agricultural revenue per hectare (S/.) |
|---|---|---|---|

| | | | |
|---|---|---|---|
| RCP 2.6 | 1 | 11.8 | 301 |
| RCP 4.5 | 1.85 | 21.7 | 556 |
| RCP 6 | 2.25 | 26.4 | 676 |
| RCP 8.5 | 3.7 | 43.5 | 1,112 |

Source: Author's elaborations bases on IPCC (2014).

It can be observed that the reduction in net agrarian revenue per hectare is between 301 soles and 1,112 soles, depending on the RCP. The above demonstrates the situation of vulnerability in which small and medium producers find themselves in Peru, and how it is going to increase as the decades go by (and the temperature increases).

# Chapter 8
# Conclusions and Limitations

The results suggest that there is a negative effect of the temperature deviation (of the long term-30 year- mean) on the net agrarian revenues of small and medium size farms in Peru. The magnitude of the effect is -6.7 percentage points over the annual net agrarian revenue per hectare. In addition, the study does not find a statistically significant effect of the precipitation deviation. Results on robust to different specifications and inclusion of outliers. In addition, the results are similar to those estimated by Seo and Mendelsohn (2007) for small farms in Latin America.

The study finds regional differences. On the Coast, the effect of temperature on agrarian revenue is 9.9 percentage points, in the Rainforest it is 4.3, and in the Highland no effects are found. These differences may be due to the occurrence of ENSO during 2017 on the Coast, as well as to heterogeneity in both soil quality and crops by region.

Finally, using the 4 RCP scenarios of the IPCC (2014), the paper estimates that by the end of the 21st century, the losses in the annual net revenue per hectare for the small and medium size farms in Peru could be between 11.8 and 43.5 percentage points. This, along with the fact that most farmers currently have agrarian revenues that place them below the poverty line, enhances their vulnerability.

It is important to note that there are several caveats that can be influencing the results. These can be categorized into data limitations and estimation limitations. On the side of data limitations, the first point to mention is the use of temperature and precipitation variables for weather. As mentioned in section 4, these are the two most commonly used variables in works that estimate the effect of weather on different economic activities. This is mainly due to the availability of data as there is a diversity of georeferenced bases with a high level of detail of these variables. However, as is mention by Zhang, Zhang and Chen (2017), weather is not only formed by these two variables. Other variables such as humidity, number of hours of sunlight and wind speed can also have a significant effect, and their omission can generate biases.

On the other hand, it is important to recognize the possible existence of measurement error in the variables. Measurement error is defined as "the difference between an observed variable and the variable that belongs in a multiple regression equation" (Wooldridge, 2016). This has two sources. The first is the ENA. This is because the farmers declare the quantities and price of their products (they are asked about the production of the last 12 months, period that may include more than one agrarian season). In this sense, it is possible that some producers are not precise declaring these values. Although a process was carried out to detect and exclude outliers, it is crucial to recognize the possible existence of errors in this variable.

The second possible source of measurement error are the weather variables. As mentioned in section 6.4, the databases used to measure weather shocks make use of various sources. Additionally, an interpolation process is performed to assign values to areas where there are no weather stations. Thus, it is possible that the values have an error as a result of this process. The use of other weather sources could allow us to measure this error and know its effect on the estimates.

On the side of the estimation limitations, the main weaknesses the use of a conglomerate panel and not at the farmer/individual panel. As mentioned above, a farmer panel would produce more accurate estimators, as the same person would be observed against different weather realizations. Currently, there is no panel of farmer that is representative of the total number of producers at the national level.

Finally, another estimation limitation of the paper is the implicit assumption that prices do not change. This can be seen in the optimization function of the Ricardian model, as producers optimize production based on an exogenous price. Changes in the weather could lead to substantial changes in production, which could lead to shortages or overproduction of certain crops. This should affect the price that producers receive and influence revenue per hectare, which is not being observed in this work.

# Appendices

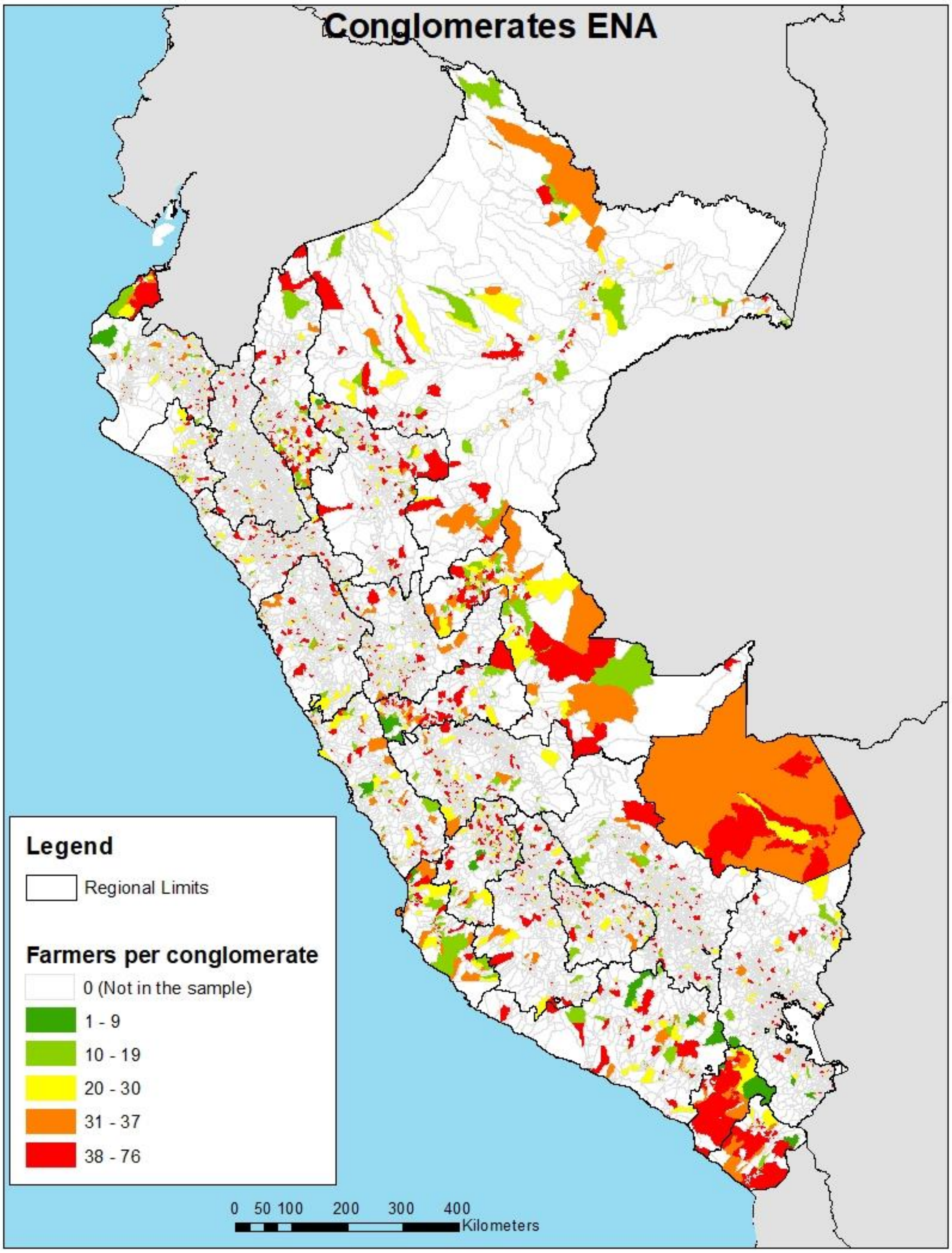
**Appendix 1: Peru Natural Regions**


Source: Author's elaborations based on CENAGRO 2012

**Appendix 2: Conglomerates Peru**


Source: Author's elaborations based on ENA

**Appendix 3: Conglomerates ENA**




Source: Author's elaborations based on ENA

### Appendix 4: Distribution of categorical variables

Education household head

| | 2015 | 2016 | 2017 | Total |
|---|---|---|---|---|
| without level | 13.2% | 12.9% | 12.9% | 13.0% |
| initial | 0.4% | 0.4% | 0.4% | 0.4% |
| incomplete primary | 31.9% | 30.8% | 30.7% | 31.1% |
| complete primary | 22.9% | 23.0% | 22.9% | 22.9% |
| incomplete secondary | 10.9% | 10.7% | 10.9% | 10.8% |
| complete secondary | 14.2% | 15.3% | 15.1% | 14.9% |
| sup. not uni. incomplete | 1.0% | 1.0% | 1.1% | 1.1% |
| sup. not uni. complete | 2.8% | 3.1% | 3.0% | 2.9% |
| sup. uni. incomplete | 0.7% | 0.7% | 0.7% | 0.7% |
| sup. uni. complete | 2.0% | 2.2% | 2.3% | 2.2% |

Source: Author's elaborations based on ENA 2015-2017.

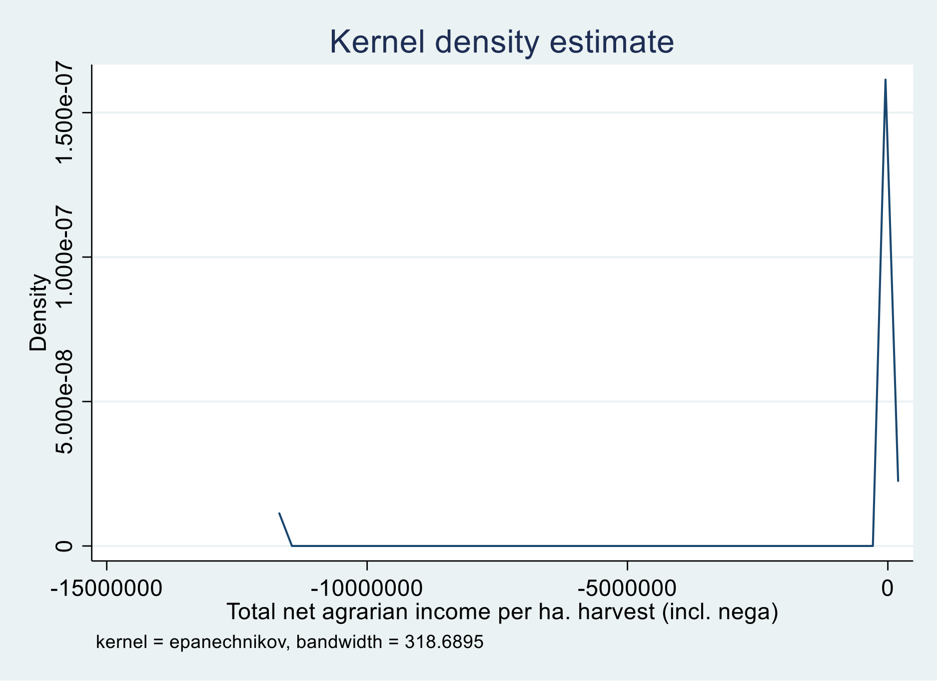
Language household head

| | 2015 | 2016 | 2017 | Total |
|---|---|---|---|---|
| quechua | 37.0% | 36.1% | 36.0% | 36.3% |
| aymara | 4.8% | 4.9% | 4.8% | 4.8% |
| other native language | 2.3% | 2.2% | 2.1% | 2.2% |
| spanish | 55.8% | 56.6% | 56.8% | 56.4% |
| portuguese | 0.1% | 0.2% | 0.2% | 0.1% |
| other foreign language | 0.0% | 0.0% | 0.0% | 0.0% |
| deaf/mute | 0.0% | 0.0% | 0.1% | 0.0% |

Source: Author's elaborations based on ENA 2015-2017.

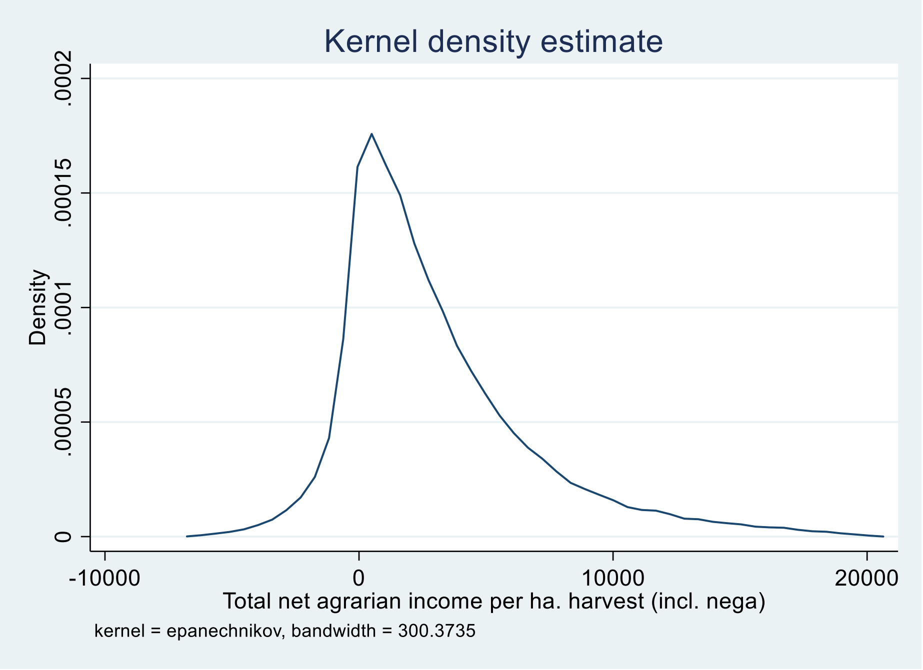
**Appendix 5: Distribution net agrarian revenue per hectare harvested**

Distribution all sample



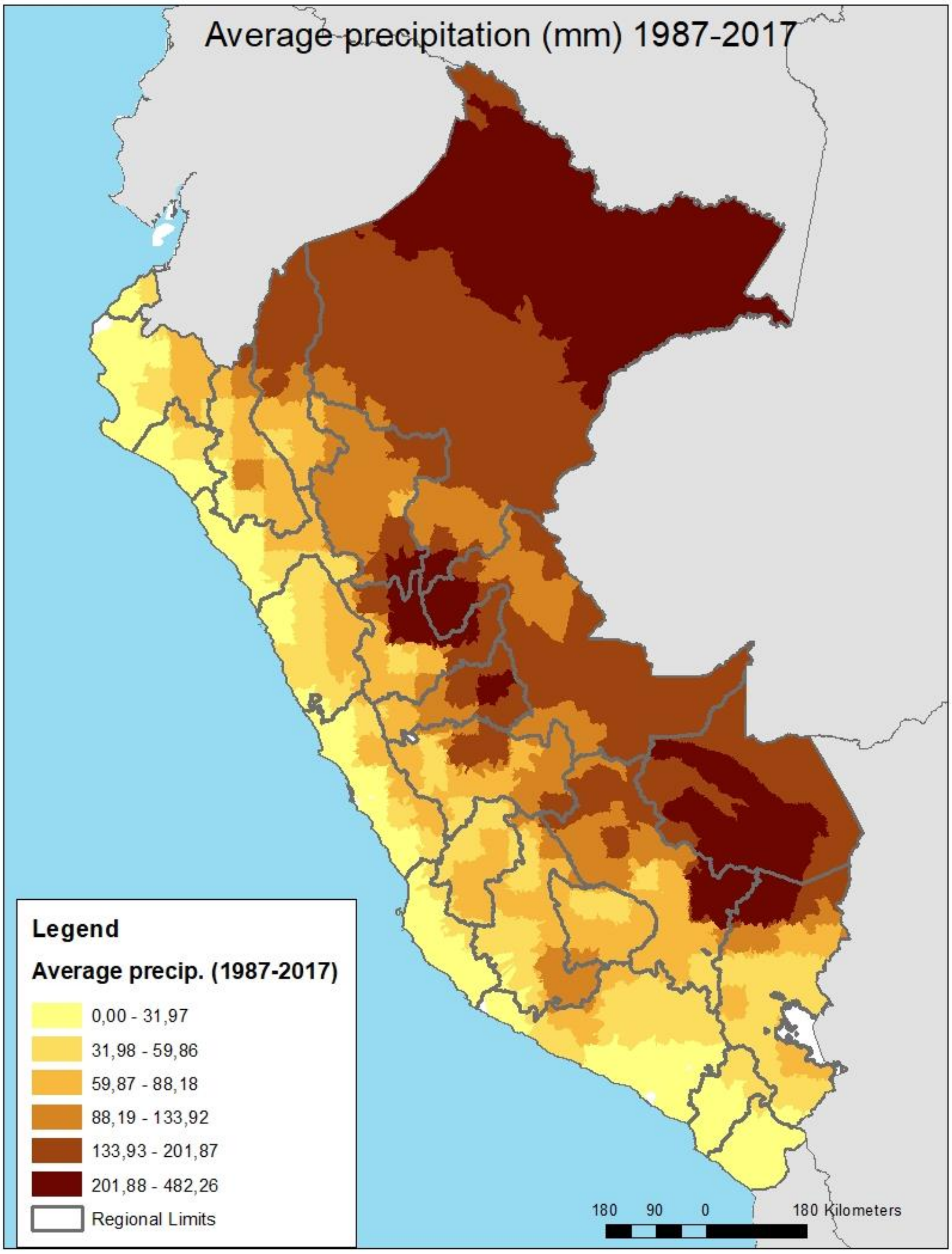

Source: Author's elaborations based on ENA 2015-2017.

Distribution after removing extremes values

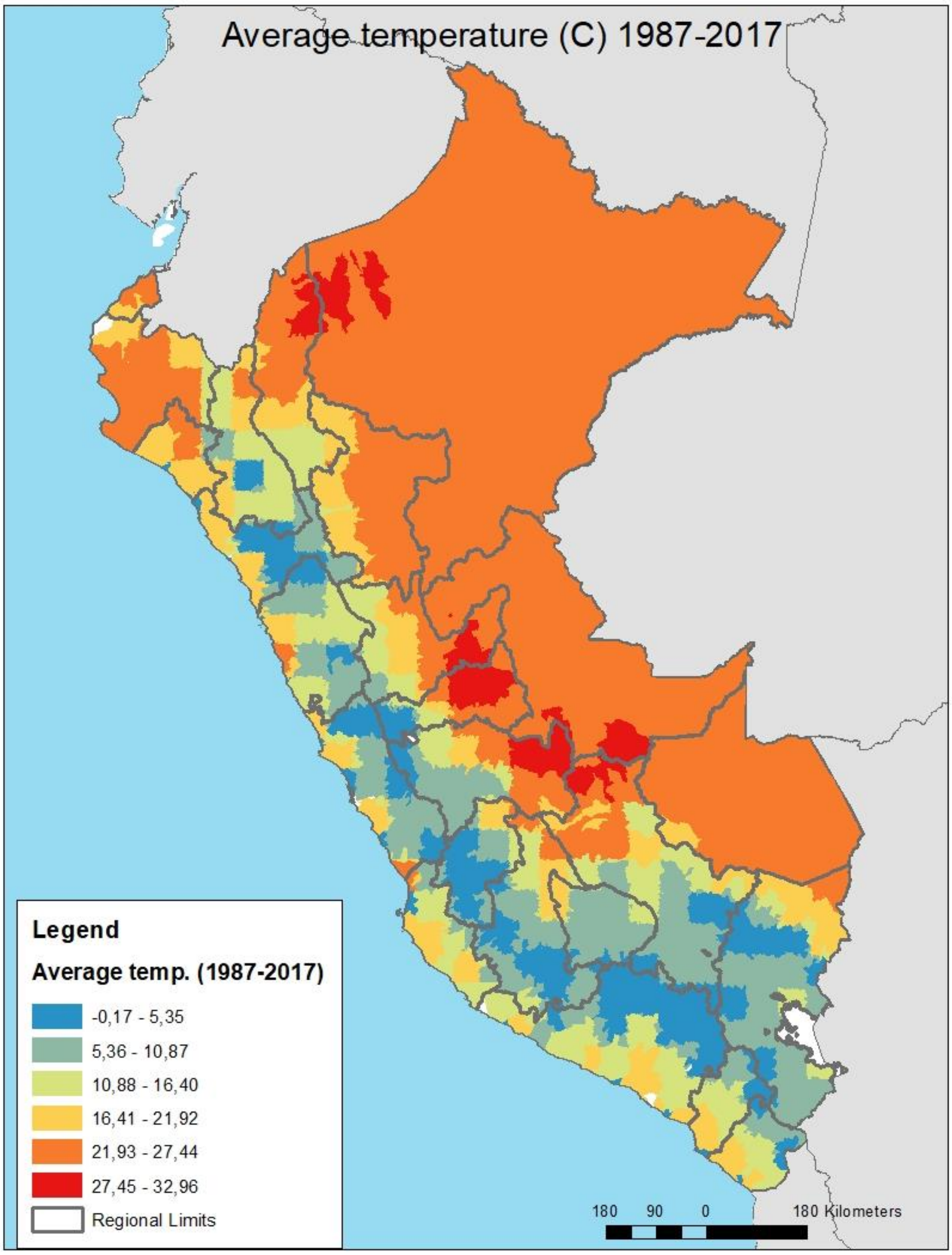



Source: Author's elaborations based on ENA 2015-2017.

**Appendix 6: Average weather 1987-2017**




Source: Author's elaborations based on Matsuura and Willmott (2018)




Source: Author's elaborations based on Matsuura and Willmott (2018)

### Appendix 7: Complete model national using the non-transform net agrarian revenue

| | | | | | |
|---|---|---|---|---|---|
| Standard Deviation precipitation (w/r 30 years) | -44.286 | -46.054 | -36.701 | -37.456 | -43.214 |
| | (50.87) | (50.74) | (50.94) | (50.97) | (51.61) |
| Standard Deviation temperature (w/r 30 years) | -211.665* | -200.861* | -213.815* | -216.391* | -189.540 |
| | (117.11) | (116.73) | (118.09) | (118.08) | (117.59) |
| Standard Deviation precipitation square (w/r 30 years) | -12.851 | -13.027 | -16.172 | -15.971 | -14.373 |
| | (16.41) | (16.37) | (16.49) | (16.49) | (16.63) |
| Standard Deviation temperature square (w/r 30 years) | -34.065 | -36.587 | -36.224 | -36.063 | -40.250 |
| | (39.31) | (39.30) | (39.47) | (39.51) | (39.50) |
| year=2015 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | (.) | (.) | (.) | (.) | (.) |
| year=2016 | 522.813*** | 513.698*** | 526.121*** | 528.923*** | 490.242*** |
| | (114.89) | (114.82) | (115.11) | (115.36) | (115.62) |
| year=2017 | 376.573*** | 375.913*** | 361.219*** | 364.421*** | 376.343*** |
| | (68.38) | (68.05) | (68.14) | (68.33) | (69.33) |
| Age household head | | -21.717*** | -24.518*** | -24.788*** | -24.534*** |
| | | (7.81) | (7.77) | (7.74) | (7.74) |
| Age square | | 0.169** | 0.199*** | 0.204*** | 0.207*** |
| | | (0.07) | (0.07) | (0.07) | (0.07) |
| Years engaged in independent agricultural activity | | 15.926*** | 13.516*** | 13.253*** | 12.007*** |
| | | (4.61) | (4.61) | (4.62) | (4.61) |
| Experience square | | -0.317*** | -0.284*** | -0.281*** | -0.265*** |
| | | (0.07) | (0.07) | (0.07) | (0.07) |
| Sex household head | | 105.507*** | 85.834** | 84.989** | 71.798** |
| | | (35.30) | (35.67) | (35.71) | (35.56) |
| HH education - Primary school or less | | -108.471*** | -111.160*** | -106.036*** | -95.583*** |
| | | (36.58) | (36.67) | (36.80) | (36.67) |
| HH language - Spanish | | 112.829 | 126.931 | 126.228 | 127.187* |
| | | (77.35) | (77.22) | (77.32) | (76.55) |
| Household head is engaged in other activities outside the farm | | -28.080 | -11.555 | -13.177 | -8.724 |
| | | (37.41) | (37.67) | (37.74) | (37.60) |
| Household size | | -6.298 | -15.350* | -16.358** | -17.129** |
| | | (7.87) | (7.96) | (7.97) | (7.92) |
| Ratio Household members over 6 years working | | -190.826** | -258.437*** | -259.155*** | -261.539*** |
| | | (97.09) | (97.46) | (97.45) | (97.34) |
| Distance to district capital (hrs.) auto report | | -11.883 | -8.855 | -8.583 | -6.586 |
| | | (10.45) | (10.42) | (10.41) | (10.43) |
| Total area | | | -1.938* | -1.957* | -1.914* |
| | | | (1.15) | (1.15) | (1.12) |
| Harvested area | | | -14.969*** | -15.902*** | -17.025*** |
| | | | (3.99) | (4.06) | (4.15) |
| Herfindahl Index crops | | | -607.810*** | -604.075*** | -558.652*** |
| | | | (100.95) | (100.80) | (101.09) |
| Total crops | | | 6.391 | 6.192 | -0.492 |
| | | | (10.66) | (10.62) | (10.65) |
| Have Technical irrigation | | | 222.725*** | 235.213*** | 178.508*** |
| | | | (63.55) | (66.13) | (68.76) |
| Farmer has received agriculture technical assistance | | | 216.345** | 194.665** | 158.670* |
| | | | (85.43) | (87.70) | (87.39) |
| Farmer has received agriculture training | | | 119.997* | 109.031* | 88.513 |
| | | | (65.79) | (64.92) | (64.29) |
| Obtain the credit | | | | 136.035** | 108.859** |
| | | | | (53.06) | (52.81) |
| Have an insurance (not health or climate) | | | | -110.323 | -123.947 |
| | | | | (118.98) | (119.38) |
| Belongs to an association, cooperative or farmers committee | | | | 56.152 | 32.411 |
| | | | | (70.56) | (70.33) |
| Belongs to the irrigation association | | | | -57.211 | -90.055 |
| | | | | (68.92) | (69.66) |
| Number of degradations practices 0-4 | | | | | -21.277 |

| | | | | | |
|---|---|---|---|---|---|
| | | | | | (28.73) |
| Number of soil cultivation practices 0-4 | | | | | -71.704*** |
| | | | | | (26.38) |
| Number of water practices 0-4 | | | | | 47.808 |
| | | | | | (34.65) |
| Number of agricultural inputs practices 0-5 | | | | | 174.073*** |
| | | | | | (23.30) |
| Constant | 2585.649*** | 3258.885*** | 3748.756*** | 3755.069*** | 3618.608*** |
| | (62.25) | (224.04) | (245.42) | (245.76) | (251.32) |
| Observations | 68578.000 | 68578.000 | 68578.000 | 68578.000 | 68578.000 |
| R2 | 0.358 | 0.360 | 0.363 | 0.363 | 0.365 |

Source: Author's elaborations. Dependent variable: net agrarian revenue per ha harvested. All estimations include conglomerate and time fixed effects. Standard error grouped at the conglomerate level in parentheses. Sig: * 0.1, ** 0.5, *** 0.01.

## Appendix 8: Full Model National using IHS transformation

| | | | | | |
|---|---|---|---|---|---|
| Standard Deviation precipitation (w/r 30 years) | -0.141 | -0.140 | -0.089 | -0.090 | -0.093 |
| | (0.10) | (0.10) | (0.10) | (0.10) | (0.10) |
| Standard Deviation temperature (w/r 30 years) | -0.016 | -0.019 | -0.112 | -0.113 | -0.097 |
| | (0.18) | (0.18) | (0.19) | (0.19) | (0.19) |
| Standard Deviation precipitation square (w/r 30 years) | -0.000 | -0.001 | -0.017 | -0.016 | -0.016 |
| | (0.03) | (0.03) | (0.03) | (0.03) | (0.03) |
| Standard Deviation temperature square (w/r 30 years) | -0.110* | -0.110* | -0.107* | -0.110* | -0.112* |
| | (0.06) | (0.06) | (0.06) | (0.06) | (0.06) |
| year=2015 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | (.) | (.) | (.) | (.) | (.) |
| year=2016 | 0.582*** | 0.599*** | 0.642*** | 0.663*** | 0.636*** |
| | (0.19) | (0.19) | (0.19) | (0.19) | (0.19) |
| year=2017 | 0.320** | 0.349*** | 0.237* | 0.252* | 0.282** |
| | (0.14) | (0.13) | (0.13) | (0.14) | (0.14) |
| Age household head | | -0.011 | -0.032** | -0.030** | -0.029** |
| | | (0.01) | (0.01) | (0.01) | (0.01) |
| Age square | | 0.000 | 0.000* | 0.000* | 0.000* |
| | | (0.00) | (0.00) | (0.00) | (0.00) |
| Years engaged in independent agricultural activity | | 0.044*** | 0.029*** | 0.030*** | 0.027*** |
| | | (0.01) | (0.01) | (0.01) | (0.01) |
| Experience square | | -0.001*** | -0.000*** | -0.000*** | -0.000*** |
| | | (0.00) | (0.00) | (0.00) | (0.00) |
| Sex household head | | 0.275*** | 0.166** | 0.177*** | 0.153** |
| | | (0.07) | (0.07) | (0.07) | (0.07) |
| HH education - Primary school or less | | 0.073 | 0.079 | 0.067 | 0.085 |
| | | (0.07) | (0.07) | (0.07) | (0.07) |
| HH language - Spanish | | -0.064 | -0.014 | -0.007 | -0.003 |
| | | (0.13) | (0.13) | (0.13) | (0.13) |
| Household head is engaged in other activities outside the farm | | -0.105 | 0.007 | 0.001 | 0.011 |
| | | (0.07) | (0.07) | (0.07) | (0.07) |
| Household size | | 0.043*** | -0.009 | -0.008 | -0.010 |
| | | (0.01) | (0.01) | (0.01) | (0.01) |
| Ratio Household members over 6 years working | | 0.072 | -0.278* | -0.282* | -0.293* |
| | | (0.17) | (0.16) | (0.16) | (0.16) |
| Distance to district capital (hrs.) auto report | | 0.021 | 0.031* | 0.030 | 0.033* |
| | | (0.02) | (0.02) | (0.02) | (0.02) |
| Total area | | | -0.007*** | -0.007*** | -0.007*** |
| | | | (0.00) | (0.00) | (0.00) |
| Harvested area | | | -0.021*** | -0.020*** | -0.022*** |
| | | | (0.01) | (0.01) | (0.01) |
| Herfindahl Index crops | | | -2.486*** | -2.487*** | -2.385*** |
| | | | (0.17) | (0.17) | (0.17) |
| Total crops | | | 0.149*** | 0.152*** | 0.139*** |
| | | | (0.02) | (0.02) | (0.02) |
| Have Technical irrigation | | | 0.742*** | 0.838*** | 0.791*** |
| | | | (0.11) | (0.11) | (0.12) |
| Farmer has received agriculture technical assistance | | | 0.157 | 0.200* | 0.131 |
| | | | (0.12) | (0.12) | (0.12) |
| Farmer has received agriculture training | | | -0.013 | 0.023 | -0.019 |
| | | | (0.10) | (0.10) | (0.10) |
| Obtain the credit | | | | -0.045 | -0.095 |
| | | | | (0.09) | (0.09) |
| Have an insurance (not health or climate) | | | | -0.211 | -0.237 |
| | | | | (0.36) | (0.36) |
| Belongs to an association, cooperative or farmers committee | | | | -0.227* | -0.276** |
| | | | | (0.12) | (0.12) |
| Belongs to the irrigation association | | | | -0.400*** | -0.404*** |
| | | | | (0.13) | (0.13) |
| Number of degradation practices 0-4 | | | | | -0.006 |
| | | | | | (0.05) |
| Number of soil cultivation practices 0-4 | | | | | -0.119** |
| | | | | | (0.05) |
| Number of water practices 0-4 | | | | | -0.042 |
| | | | | | (0.05) |
| Number of agricultural inputs practices 0-5 | | | | | 0.345*** |
| | | | | | (0.04) |
| Constant | 5.343*** | 4.757*** | 6.878*** | 6.912*** | 6.607*** |
| | (0.12) | (0.41) | (0.44) | (0.44) | (0.45) |
| Observations | 68578.000 | 68578.000 | 68578.000 | 68578.000 | 68578.000 |

| | | | | | |
|---|---|---|---|---|---|
| R2 | 0.268 | 0.269 | 0.289 | 0.290 | 0.292 |

Source: Author's elaborations. Dependent variable: IHS transformation of the net agrarian revenue per ha harvested. All estimations include conglomerate and time fixed effects. Standard error grouped at the conglomerate level in parentheses. Sig: * 0.1, ** 0.5, *** 0.01.

### Appendix 9: Full Model National using IHS transformation with extreme values

| | | | | | |
|---|---|---|---|---|---|
| Standard Deviation precipitation (w/r 30 years) | -0.142 | -0.140 | -0.085 | -0.086 | -0.086 |
| | (0.11) | (0.11) | (0.11) | (0.11) | (0.11) |
| Standard Deviation temperature (w/r 30 years) | -0.097 | -0.103 | -0.203 | -0.203 | -0.211 |
| | (0.19) | (0.19) | (0.19) | (0.19) | (0.20) |
| Standard Deviation precipitation square (w/r 30 years) | 0.014 | 0.014 | -0.005 | -0.004 | -0.006 |
| | (0.03) | (0.03) | (0.03) | (0.03) | (0.03) |
| Standard Deviation temperature square (w/r 30 years) | -0.110* | -0.109* | -0.104* | -0.106* | -0.104 |
| | (0.06) | (0.06) | (0.06) | (0.06) | (0.06) |
| year=2015 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | (.) | (.) | (.) | (.) | (.) |
| year=2016 | 0.836*** | 0.863*** | 0.885*** | 0.900*** | 0.901*** |
| | (0.19) | (0.19) | (0.19) | (0.19) | (0.20) |
| year=2017 | 0.288** | 0.326** | 0.188 | 0.198 | 0.237 |
| | (0.14) | (0.15) | (0.14) | (0.14) | (0.15) |
| Age household head | | -0.012 | -0.037** | -0.035** | -0.035** |
| | | (0.02) | (0.01) | (0.01) | (0.01) |
| Age square | | 0.000 | 0.000** | 0.000* | 0.000* |
| | | (0.00) | (0.00) | (0.00) | (0.00) |
| Years engaged in independent agricultural activity | | 0.057*** | 0.040*** | 0.041*** | 0.038*** |
| | | (0.01) | (0.01) | (0.01) | (0.01) |
| Experience square | | -0.001*** | -0.001*** | -0.001*** | -0.001*** |
| | | (0.00) | (0.00) | (0.00) | (0.00) |
| Sex household head | | 0.401*** | 0.269*** | 0.279*** | 0.254*** |
| | | (0.07) | (0.07) | (0.07) | (0.07) |
| HH education - Primary school or less | | 0.073 | 0.091 | 0.078 | 0.096 |
| | | (0.07) | (0.07) | (0.07) | (0.07) |
| HH language - Spanish | | -0.057 | -0.006 | 0.002 | 0.003 |
| | | (0.13) | (0.13) | (0.13) | (0.13) |
| Household head is engaged in other activities outside the farm | | -0.193*** | -0.056 | -0.059 | -0.048 |
| | | (0.07) | (0.07) | (0.07) | (0.07) |
| Household size | | 0.050*** | -0.010 | -0.008 | -0.011 |
| | | (0.02) | (0.01) | (0.01) | (0.01) |
| Ratio Household members over 6 years working | | 0.260 | -0.102 | -0.102 | -0.118 |
| | | (0.17) | (0.17) | (0.17) | (0.17) |
| Distance to district capital (hrs.) auto report | | 0.025 | 0.038* | 0.036* | 0.041** |
| | | (0.02) | (0.02) | (0.02) | (0.02) |
| Total area | | | -0.009*** | -0.009*** | -0.009*** |
| | | | (0.00) | (0.00) | (0.00) |
| Harvested area | | | -0.000 | 0.001 | -0.001 |
| | | | (0.01) | (0.01) | (0.01) |
| Herfindahl Index crops | | | -2.392*** | -2.394*** | -2.294*** |
| | | | (0.17) | (0.17) | (0.17) |
| Total crops | | | 0.195*** | 0.198*** | 0.184*** |
| | | | (0.02) | (0.02) | (0.02) |
| Have Technical irrigation | | | 0.964*** | 1.028*** | 0.995*** |
| | | | (0.12) | (0.12) | (0.13) |
| Farmer has received agriculture technical assistance | | | 0.100 | 0.144 | 0.075 |
| | | | (0.13) | (0.13) | (0.13) |
| Farmer has received agriculture training | | | 0.015 | 0.049 | 0.003 |
| | | | (0.11) | (0.11) | (0.11) |
| Obtain the credit | | | | -0.137 | -0.189** |
| | | | | (0.10) | (0.10) |
| Have an insurance (not health or climate) | | | | -0.173 | -0.207 |
| | | | | (0.34) | (0.34) |
| Belongs to an association, cooperative or farmers committee | | | | -0.188 | -0.236* |
| | | | | (0.12) | (0.12) |
| Belongs to the irrigation association | | | | -0.277** | -0.262* |
| | | | | (0.13) | (0.14) |
| Number of degradation practices 0-4 | | | | | -0.008 |
| | | | | | (0.06) |
| Number of soil cultivation practices 0-4 | | | | | -0.097** |
| | | | | | (0.05) |
| Number of water practices 0-4 | | | | | -0.092* |
| | | | | | (0.05) |
| Number of agricultural inputs practices 0-5 | | | | | 0.366*** |
| | | | | | (0.04) |
| Constant | 4.950*** | 4.005*** | 6.019*** | 6.049*** | 5.703*** |
| | (0.13) | (0.42) | (0.45) | (0.46) | (0.47) |
| Observations | 74565.000 | 74565.000 | 74565.000 | 74565.000 | 74565.000 |

| | | | | | |
|---|---|---|---|---|---|
| R2 | 0.247 | 0.250 | 0.271 | 0.271 | 0.273 |

Source: Author's elaborations. Dependent variable: inverse hyperbolic sine transformation of the net agrarian revenue per ha harvested. Coefficients transformed using equation 6-3. All estimations include conglomerate and time fixed effects. Standard error grouped at the conglomerate level in parentheses. Sig: * 0.1, ** 0.5, *** 0.01.

## Appendix 10: Full Model Coast

| | | | | | |
|---|---|---|---|---|---|
| Standard Deviation precipitation (w/r 30 years) | -0.080 | -0.035 | -0.004 | -0.006 | -0.029 |
| | (0.17) | (0.17) | (0.17) | (0.17) | (0.17) |
| Standard Deviation temperature (w/r 30 years) | -0.421 | -0.519 | -0.548 | -0.555 | -0.367 |
| | (0.44) | (0.43) | (0.42) | (0.42) | (0.43) |
| Standard Deviation precipitation square (w/r 30 years) | -0.001 | -0.007 | -0.006 | -0.006 | 0.001 |
| | (0.04) | (0.04) | (0.04) | (0.04) | (0.04) |
| Standard Deviation temperature square (w/r 30 years) | -0.127 | -0.108 | -0.114 | -0.113 | -0.162 |
| | (0.14) | (0.13) | (0.13) | (0.13) | (0.13) |
| year=2015 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | (.) | (.) | (.) | (.) | (.) |
| year=2016 | 0.941*** | 0.982*** | 1.008*** | 1.008*** | 0.951*** |
| | (0.20) | (0.20) | (0.20) | (0.20) | (0.21) |
| year=2017 | 0.051 | -0.007 | -0.128 | -0.128 | -0.115 |
| | (0.27) | (0.28) | (0.27) | (0.27) | (0.26) |
| Age household head | | 0.052 | 0.044 | 0.045 | 0.044 |
| | | (0.03) | (0.03) | (0.03) | (0.03) |
| Age square | | -0.000* | -0.000 | -0.000 | -0.000 |
| | | (0.00) | (0.00) | (0.00) | (0.00) |
| Years engaged in independent agricultural activity | | 0.013 | 0.005 | 0.005 | 0.004 |
| | | (0.01) | (0.01) | (0.01) | (0.01) |
| Experience square | | -0.000 | -0.000 | -0.000 | -0.000 |
| | | (0.00) | (0.00) | (0.00) | (0.00) |
| Sex household head | | 0.221* | 0.115 | 0.117 | 0.084 |
| | | (0.13) | (0.13) | (0.13) | (0.13) |
| HH education - Primary school or less | | 0.022 | 0.081 | 0.078 | 0.086 |
| | | (0.12) | (0.12) | (0.12) | (0.12) |
| HH language - Spanish | | 0.158 | 0.213 | 0.215 | 0.202 |
| | | (0.29) | (0.29) | (0.29) | (0.29) |
| Household head is engaged in other activities outside the farm | | 0.033 | 0.115 | 0.114 | 0.124 |
| | | (0.13) | (0.13) | (0.13) | (0.13) |
| Household size | | 0.022 | 0.001 | 0.002 | 0.000 |
| | | (0.03) | (0.03) | (0.03) | (0.03) |
| Ratio Household members over 6 years working | | -0.043 | -0.090 | -0.090 | -0.119 |
| | | (0.21) | (0.21) | (0.21) | (0.21) |
| Distance to district capital (hrs.) auto report | | -0.283** | -0.293** | -0.294** | -0.289** |
| | | (0.12) | (0.12) | (0.12) | (0.12) |
| Total area | | | 0.001 | 0.001 | 0.000 |
| | | | (0.00) | (0.00) | (0.00) |
| Harvested area | | | 0.057*** | 0.058*** | 0.054*** |
| | | | (0.01) | (0.01) | (0.01) |
| Herfindahl Index crops | | | -1.693*** | -1.699*** | -1.744*** |
| | | | (0.32) | (0.32) | (0.32) |
| Total crops | | | 0.033 | 0.033 | 0.030 |
| | | | (0.02) | (0.02) | (0.02) |
| Have Technical irrigation | | | 0.126 | 0.125 | -0.106 |
| | | | (0.18) | (0.18) | (0.18) |
| Farmer has received agriculture technical assistance | | | 0.269 | 0.291 | 0.246 |
| | | | (0.19) | (0.19) | (0.19) |
| Farmer has received agriculture training | | | 0.170 | 0.191 | 0.181 |
| | | | (0.19) | (0.19) | (0.19) |
| Obtain the credit | | | | -0.055 | -0.078 |
| | | | | (0.11) | (0.11) |
| Have an insurance (not health or climate) | | | | 0.191 | 0.166 |
| | | | | (0.44) | (0.43) |
| Belongs to an association, cooperative or farmers committee | | | | -0.124 | -0.195 |
| | | | | (0.24) | (0.24) |
| Belongs to the irrigation association | | | | -0.017 | -0.117 |
| | | | | (0.24) | (0.24) |
| Number of degradation practices 0-4 | | | | | -0.171* |
| | | | | | (0.10) |
| Number of soil cultivation practices 0-4 | | | | | 0.123** |
| | | | | | (0.06) |
| Number of water practices 0-4 | | | | | 0.093 |
| | | | | | (0.07) |
| Number of agricultural inputs practices 0-5 | | | | | 0.272*** |
| | | | | | (0.09) |
| Constant | 8.303*** | 6.513*** | 7.889*** | 7.900*** | 7.286*** |

| | | | | | |
|---|---|---|---|---|---|
| | (0.30) | (0.92) | (0.95) | (0.96) | (0.96) |
| Observations | 11149.000 | 11149.000 | 11149.000 | 11149.000 | 11149.000 |
| R2 | 0.185 | 0.188 | 0.202 | 0.202 | 0.205 |

Source: Author's elaborations. Dependent variable: IHS transformation of the net agrarian revenue per ha harvested. All estimations include conglomerate and time fixed effects. Standard error grouped at the conglomerate level in parentheses. Sig: * 0.1, ** 0.5, *** 0.01.

## Appendix 11: Full Model Highlands

| | | | | | |
|---|---|---|---|---|---|
| Standard Deviation precipitation (w/r 30 years) | -0.197 | -0.200 | -0.143 | -0.144 | -0.142 |
| | (0.14) | (0.14) | (0.14) | (0.14) | (0.14) |
| Standard Deviation temperature (w/r 30 years) | 0.326 | 0.321 | 0.355 | 0.362 | 0.293 |
| | (0.32) | (0.32) | (0.32) | (0.32) | (0.33) |
| Standard Deviation precipitation square (w/r 30 years) | -0.006 | -0.005 | -0.031 | -0.028 | -0.030 |
| | (0.04) | (0.04) | (0.04) | (0.04) | (0.04) |
| Standard Deviation temperature square (w/r 30 years) | -0.147 | -0.143 | -0.172* | -0.179* | -0.158 |
| | (0.10) | (0.10) | (0.10) | (0.10) | (0.10) |
| year=2015 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | (.) | (.) | (.) | (.) | (.) |
| year=2016 | 0.235 | 0.238 | 0.168 | 0.200 | 0.207 |
| | (0.33) | (0.33) | (0.33) | (0.33) | (0.33) |
| year=2017 | 0.271 | 0.305* | 0.116 | 0.140 | 0.175 |
| | (0.18) | (0.18) | (0.18) | (0.18) | (0.18) |
| Age household head | | -0.013 | -0.042* | -0.038* | -0.039* |
| | | (0.02) | (0.02) | (0.02) | (0.02) |
| Age square | | 0.000 | 0.000* | 0.000 | 0.000* |
| | | (0.00) | (0.00) | (0.00) | (0.00) |
| Years engaged in independent agricultural activity | | 0.062*** | 0.041*** | 0.042*** | 0.039*** |
| | | (0.01) | (0.01) | (0.01) | (0.01) |
| Experience square | | -0.001*** | -0.001*** | -0.001*** | -0.001*** |
| | | (0.00) | (0.00) | (0.00) | (0.00) |
| Sex household head | | 0.321*** | 0.145* | 0.160* | 0.140 |
| | | (0.09) | (0.09) | (0.09) | (0.09) |
| HH education - Primary school or less | | 0.051 | 0.098 | 0.085 | 0.095 |
| | | (0.10) | (0.10) | (0.10) | (0.10) |
| HH language - Spanish | | -0.039 | 0.013 | 0.025 | 0.025 |
| | | (0.18) | (0.18) | (0.18) | (0.18) |
| Household head is engaged in other activities outside the farm | | -0.104 | 0.078 | 0.068 | 0.079 |
| | | (0.10) | (0.10) | (0.10) | (0.10) |
| Household size | | 0.052** | -0.017 | -0.016 | -0.019 |
| | | (0.02) | (0.02) | (0.02) | (0.02) |
| Ratio Household members over 6 years working | | -0.180 | -0.687*** | -0.691*** | -0.669** |
| | | (0.27) | (0.26) | (0.26) | (0.26) |
| Distance to district capital (hrs.) auto report | | 0.048 | 0.072** | 0.069** | 0.075** |
| | | (0.03) | (0.03) | (0.03) | (0.03) |
| Total area | | | -0.005 | -0.005 | -0.005 |
| | | | (0.00) | (0.00) | (0.00) |
| Harvested area | | | 0.011 | 0.013 | 0.010 |
| | | | (0.02) | (0.02) | (0.02) |
| Herfindahl Index crops | | | -2.814*** | -2.812*** | -2.676*** |
| | | | (0.23) | (0.23) | (0.23) |
| Total crops | | | 0.199*** | 0.204*** | 0.189*** |
| | | | (0.03) | (0.03) | (0.03) |
| Have Technical irrigation | | | 0.725*** | 0.861*** | 0.864*** |
| | | | (0.12) | (0.13) | (0.14) |
| Farmer has received agriculture technical assistance | | | 0.013 | 0.059 | 0.007 |
| | | | (0.24) | (0.24) | (0.24) |
| Farmer has received agriculture training | | | -0.064 | -0.013 | -0.057 |
| | | | (0.18) | (0.18) | (0.18) |
| Obtain the credit | | | | 0.057 | 0.005 |
| | | | | (0.15) | (0.15) |
| Have an insurance (not health or climate) | | | | -0.260 | -0.281 |
| | | | | (0.41) | (0.40) |
| Belongs to an association, cooperative or farmers committee | | | | -0.360* | -0.378* |
| | | | | (0.21) | (0.21) |
| Belongs to the irrigation association | | | | -0.540*** | -0.508*** |
| | | | | (0.15) | (0.15) |
| Number of degradation practices 0-4 | | | | | 0.016 |
| | | | | | (0.07) |
| Number of soil cultivation practices 0-4 | | | | | -0.182*** |
| | | | | | (0.06) |
| Number of water practices 0-4 | | | | | -0.113* |
| | | | | | (0.07) |
| Number of agricultural inputs practices 0-5 | | | | | 0.372*** |
| | | | | | (0.06) |
| Constant | 4.093*** | 3.447*** | 5.797*** | 5.811*** | 5.634*** |
| | (0.19) | (0.63) | (0.65) | (0.65) | (0.67) |
| Observations | 41599.000 | 41599.000 | 41599.000 | 41599.000 | 41599.000 |

| | | | | | |
|---|---|---|---|---|---|
| R2 | 0.220 | 0.222 | 0.246 | 0.247 | 0.249 |

Source: Author's elaborations. Dependent variable: IHS transformation of the net agrarian revenue per ha harvested. All estimations include conglomerate and time fixed effects. Standard error grouped at the conglomerate level in parentheses. Sig: * 0.1, ** 0.5, *** 0.01.

## Appendix 12: Full Model Rainforest

| | | | | | |
|---|---|---|---|---|---|
| Standard Deviation precipitation (w/r 30 years) | -0.009 | -0.001 | 0.040 | 0.039 | 0.024 |
| | (0.10) | (0.10) | (0.10) | (0.10) | (0.10) |
| Standard Deviation temperature (w/r 30 years) | -0.333* | -0.348* | -0.485** | -0.480** | -0.424** |
| | (0.20) | (0.20) | (0.21) | (0.21) | (0.21) |
| Standard Deviation precipitation square (w/r 30 years) | 0.016 | 0.013 | -0.003 | -0.003 | -0.007 |
| | (0.05) | (0.05) | (0.05) | (0.05) | (0.05) |
| Standard Deviation temperature square (w/r 30 years) | 0.044 | 0.040 | 0.054 | 0.055 | 0.038 |
| | (0.06) | (0.07) | (0.07) | (0.07) | (0.07) |
| year=2015 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| | (.) | (.) | (.) | (.) | (.) |
| year=2016 | 0.516* | 0.600** | 0.785*** | 0.764** | 0.733** |
| | (0.30) | (0.30) | (0.30) | (0.31) | (0.31) |
| year=2017 | 0.323** | 0.376** | 0.425*** | 0.418*** | 0.448*** |
| | (0.15) | (0.15) | (0.16) | (0.16) | (0.16) |
| Age household head | | -0.031* | -0.035* | -0.032* | -0.032* |
| | | (0.02) | (0.02) | (0.02) | (0.02) |
| Age square | | 0.000 | 0.000 | 0.000 | 0.000 |
| | | (0.00) | (0.00) | (0.00) | (0.00) |
| Years engaged in independent agricultural activity | | 0.014 | 0.010 | 0.011 | 0.009 |
| | | (0.01) | (0.01) | (0.01) | (0.01) |
| Experience square | | -0.000 | -0.000 | -0.000 | -0.000 |
| | | (0.00) | (0.00) | (0.00) | (0.00) |
| Sex household head | | 0.085 | 0.117 | 0.118 | 0.102 |
| | | (0.11) | (0.10) | (0.10) | (0.10) |
| HH education - Primary school or less | | 0.145* | 0.092 | 0.084 | 0.107 |
| | | (0.08) | (0.08) | (0.08) | (0.08) |
| HH language - Spanish | | -0.143 | -0.103 | -0.112 | -0.108 |
| | | (0.19) | (0.17) | (0.17) | (0.17) |
| Household head is engaged in other activities outside the farm | | -0.191** | -0.203*** | -0.199*** | -0.193*** |
| | | (0.08) | (0.07) | (0.07) | (0.07) |
| Household size | | 0.035* | 0.016 | 0.018 | 0.019 |
| | | (0.02) | (0.02) | (0.02) | (0.02) |
| Ratio Household members over 6 years working | | 0.786*** | 0.619** | 0.620** | 0.611** |
| | | (0.27) | (0.26) | (0.26) | (0.26) |
| Distance to district capital (hrs.) auto report | | 0.007 | 0.009 | 0.008 | 0.009 |
| | | (0.02) | (0.02) | (0.02) | (0.02) |
| Total area | | | -0.010*** | -0.010*** | -0.010*** |
| | | | (0.00) | (0.00) | (0.00) |
| Harvested area | | | -0.032*** | -0.031*** | -0.032*** |
| | | | (0.01) | (0.01) | (0.01) |
| Herfindahl Index crops | | | -1.496*** | -1.502*** | -1.469*** |
| | | | (0.21) | (0.21) | (0.22) |
| Total crops | | | 0.061** | 0.062*** | 0.056** |
| | | | (0.02) | (0.02) | (0.02) |
| Have Technical irrigation | | | 1.168*** | 1.059*** | 0.779*** |
| | | | (0.28) | (0.30) | (0.29) |
| Farmer has received agriculture technical assistance | | | 0.241* | 0.271* | 0.224 |
| | | | (0.13) | (0.14) | (0.14) |
| Farmer has received agriculture training | | | 0.008 | 0.023 | 0.007 |
| | | | (0.12) | (0.11) | (0.11) |
| Obtain the credit | | | | -0.316** | -0.364*** |
| | | | | (0.14) | (0.14) |
| Have an insurance (not health or climate) | | | | -0.403 | -0.524 |
| | | | | (1.11) | (1.07) |
| Belongs to an association, cooperative or farmers committee | | | | -0.011 | -0.050 |
| | | | | (0.13) | (0.12) |
| Belongs to the irrigation association | | | | 0.390 | 0.168 |
| | | | | (0.45) | (0.48) |
| Number of degradation practices 0-4 | | | | | -0.015 |
| | | | | | (0.08) |
| Number of soil cultivation practices 0-4 | | | | | -0.066 |
| | | | | | (0.05) |
| Number of water practices 0-4 | | | | | 0.212** |
| | | | | | (0.09) |
| Number of agricultural inputs practices 0-5 | | | | | 0.202*** |
| | | | | | (0.05) |
| Constant | 7.714*** | 7.663*** | 9.043*** | 9.019*** | 8.829*** |
| | (0.10) | (0.46) | (0.50) | (0.50) | (0.50) |
| Observations | 15830.000 | 15830.000 | 15830.000 | 15830.000 | 15830.000 |

| | | | | | |
|---|---|---|---|---|---|
| R2 | 0.138 | 0.142 | 0.173 | 0.174 | 0.177 |

Source: Author's elaborations. Dependent variable: IHS transformation of the net agrarian revenue per ha harvested. All estimations include conglomerate and time fixed effects. Standard error grouped at the conglomerate level in parentheses. Sig: * 0.1, ** 0.5, *** 0.01.

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# Notes

[1] El Niño-Southern Oscillation (ENSO) is a climate phenomenon characterized by the increase in sea temperature on the north coast of the country, which causes heavy rains in this region.

[2] The National Agrarian Survey (ENA, main source of data of this paper) uses 50 hectares to separate small and medium sized farmers from large farmers.

[3] A synthetic index that takes into account all kinds of agricultural units, small and large, and that varies from 0 to 1 when inequality increases, so that closer to 1 means that there is greater concentration of the means of production.

[4] Phenomenon by which the land is divided so that it can be given in inheritance to more than 1 son.

[5] The database assigns the following criteria in each category: "No or slight limitations", "Moderate limitations", "Sever limitations", "Very severe limitations", "Mainly non-soil", "Permafrost area" and "Water bodies"

[6] The net present value is equal to $\sum \pi^{-\theta t}$ . Where $\pi$ is the net agrarian value, $\theta$ is the discount rate and $t$ is the time. (Mendelsohn, Nordhaus and Shaw, 1994)

[7] As an example, Blanc and Schlenker (2017), mention that if the increase of temperature can generate a plague. The farmers would have to use a pesticide to maintain his production. The traditional model would not capture this (because the productivity would be the same) but if the Ricardian model (because it includes the cost of the input inside net agrarian revenues).

[8] Some literature refers as *Semi-Ricardian* approach to models that use revenue instead of land value (Guiteras, 2009)

[9]Burkina Faso, Cameroon, Egypt, Ethiopia, Ghana, Kenya, Niger, Senegal, South Africa, Zambia, and Zimbabwe

[10] Argentina, Brazil, Chile, Colombia, Ecuador, Uruguay, and Venezuela.

[11] The year 2014 is not taken into account since a different sampling design was made that year

[12] The conglomerates are groups of the Agricultural Census Sector´s (SEA for its Spanish acronym). The SEA´s are the georeferenced minimum units of the agricultural census. There are 19,264 conglomerates in Peru with an average area of 66 square kilometers and occupied by 120 producers. Appendix 2 shows a map of all conglomerates, while Appendix 3 shows a map of the conglomerates present in the pool, with the total number of farmers

[13] The agrarian activity is that related to the sowing and harvest of crops. The agricultural activity includes the agrarian activity, as well as the livestock activities (INEI, 2013).

[14] The method consists of standardizing each variable so that they have a mean of 0 and a standard deviation of 1, then for each variable the Modified Z-scores is estimated as: $M_{i=} \frac{0.6745(x_i-\tilde{x})}{MAD}$ where MAD is the median absolute deviation of the variable $x$, and $\tilde{x}$ is the median of that variable. Observations with an $M$ value greater than 3.5 are considered as an outlier.

[15] Although, as already mentioned, the results are robust even when the third cut is not applied, as can be seen in the appendix 9.

[16] The ENA collects information on the following agrarian inputs: land leasing, temporary and permanent labour, irrigation water, technical assistance, purchase of agrarian equipment and machinery, rental or maintenance of agrarian equipment, fuel and other agrarian expenses.

[17] The annual inflation used is that given by the Central Bank of Reserve of Peru. The 2016 inflation was 3.2% and the 2017 inflation was 1.4%. Thus 2016 values were divided by 1.032 and 2017 values by (1.014*1.032).

[18] The average annual exchange rate (sol-dollar) of 2015 of the BCRP is used for the conversion. This is equal to 3.06.

[19] The poverty line is the monetary value against which a household's monthly per capita expenditure is compared to determine whether it is in poverty or not. In Peru, each sub-region has a dif-

ferent value (because geographical inflation is taken into account). For this paper the simple average of the subregions (excluding Lima, the capital city) was used to build the poverty line of the reference region.

[20] A shapefile is a GIS file that contains information about the shape of the conglomerates, as well as their location

[21] In this example the brown area equals 22% of the total area, while the green and the purple area represents the 58% and the 20% of the total area, respectively. Therefore, the weighted average is: (361.4*0.22 + 327.1*0.58 + 355.6*0.2) = 340.2

[22] The standard deviation per year was estimated using the following formula: $SD_i = \frac{M_i - M_{30}}{SD_{30}}$. Where SD is the standard deviation of the year i, Mi is the mean for the year i, M30 is the average of the last 30 year and SD30 is the standard deviation of the last 30 year.

[23] Logarithms are only defined for positive numbers.

[24] The standard interpretation of a log-linear model.

[25] The paper of Bellemare and Wichman (2019) use the following formula to estimate the elasticity in a HIS model: $\varepsilon_{yc} = \hat{B}\bar{C}\frac{\sqrt{\bar{y}^2+1}}{\bar{y}}$ . Since in our case we have a model with a linear term and a quadratic term the first derivative is applied to equation 6-1 $dy/dC = \hat{B} + 2\hat{\gamma}$ and on it component of the right size of the derivative the the transformation is applied.

[26] "The index is given as $HI\colon \sum_{i=1}^{N} P_i^2$ Where N is the total number of crops and Pi represents area proportion of the i-th crop in total cropped area" (Pal and Kar, 2012, p. 99)

[27] The difference between technical assistance and capacitation is that the first is necessarily provided in the field (INEI, 2017b)