Blame it on the Rain: The Effects of Weather Shocks on Formal Rural Employment in Colombia

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Abstract

Episodes of excessive or low rainfall have not only become more frequent, but also more severe. These events can affect agricultural production and local labor markets. By combining social security records, that allow us to measure formal employment in rural areas and average earnings, with administrative data from weather stations, we estimate the effects of municipality-level precipitation shocks on formal rural employment in Colombia and the heterogeneous effects of having access to irrigation technologies for mitigating these shocks. Additionally, we explore if such weather shocks translate into productivity shocks by looking at price changes in some agricultural goods. Fixed effect estimates show that monthly episodes of excessive rainfall—measured as those that are above the 90th percentile of historical mean precipitation in the last 30 years for each municipality—have a negative impact on formal employment in rural areas for both the agricultural and non-agricultural sector, On the other hand, episodes of lack of rainfall (i.e., below the 10th percentile) affect the formal rural labor market in the opposite direction. We also find heterogeneous effects by type of crop. Last, but not least, episodes of lack of rainfall are related with higher food prices, indicating they are acting as negative productivity shocks.

Keywords: Formal labor market, employment, weather shocks, agriculture, Colombia
JEL Classification: J20, J30, J43, J46, Q54, R23

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1 Introduction

Households located in rural areas in developing countries are exposed to a handful of shocks, such as conflict, crop plagues, natural disasters, and climate change (Jayachandran, 2006; Maccini and Yang, 2009; Fernández, Ibáñez, and Peña, 2014; Calderón-Mejia and Ibáñez, 2016; Quinones, 2018). In particular, unexpected rain patterns could act as negative productivity shocks, causing large changes in wages and employment, especially when workers are poorer, less able to migrate, and more credit-constrained because they face an inelastic labor supply curve (Jayachandran, 2006; Quinones, 2018; Colmer, 2019).

The negative impact of unexpected rain shocks depends on when they happen during the crops cycle. If there is rain during harvest season, then the crops could be damaged. But if there is no rain during the seed sowing and irrigation season, in particular in areas where there are no irrigation systems, then the crops are going to have a poor performance. Thus, predictable rain patterns are necessary for agricultural production as farmers need to plan accordingly. Therefore, bad weather shocks can potentially lower agricultural labor productivity as they lower crops' yield (Chaurey, 2015; Adhvaryu, Chari, and Sharma, 2013).

In this paper, we estimate the effect of rain shocks, defined as episodes of monthly precipitation that are above the 90th percentile or below the 10th percentile of mean precipitation in the last 30 years for each municipality, on formal employment and earnings of workers located in rural areas for Colombia as we would like to understand the role that rain shocks could have on formal job creation in rural areas, given that labor informality is one of the main issues of rural labor markets in Colombia (Leibovich et al., 2006; Merchán et al., 2015; Otero-Cortés, 2019). We define formal workers as those who make monthly contributions to the social security system (health and pensions).

We focus on Colombia for two reasons. First, the country is highly exposed to intense rainy periods and longer than usual dry summer seasons, known as “Fenómeno de la Niña” and “Fenómeno del Niño”, respectively, which seem to be getting more severe in time due to climate change, given that this phenomena happen as a consequence of the cooling and warming patterns of the Pacific Ocean (Sanchez-Jabba et al., 2014).

For example, between 2010-2011, Colombia underwent the worst episode of La Niña phenomenon of recent times. As a result of the prolonged rain, there were several floods that dramatically hit municipalities located on the margins of the main rivers of the country. This natural disaster affected approximately 7% of the population of the country and 80 percent of the municipalities (Sanchez-Jabba et al., 2014). On the other hand, during 2015-2016, the country experienced a severe El Niño episode—or extended dry season—that left the Magdalena River, which is the main river that crosses the country, at its lowest historical levels and more than half of the municipalities of the country experienced water scarcity and fires.

Second, there is extensive evidence of the effect of rain shocks on agricultural productivity, wages and employment for Southeast Asia. Less is known about its effects on other regions of the world with different climate and geographic conditions.Therefore, we hypothesize that rain shocks translate into less available employment and lower wages as there is a reduced demand for labor at harvest time assuming that the labor supply remains unchanged. This situation is very frequent in poor rural communities as they live at the subsistence level and do not have access to smoothing mechanisms such as the credit market or the income necessary in order to migrate that could help them reduce the quantity of labor they are supplying to the labor market when wages are low. Instead, in their case, the income effect dominates the substitution effect and they end up supplying even more labor to compensate the drop in earnings (Jayachandran, 2006).

For our empirical strategy, we use two different sources of administrative data for our estimations: data from the Colombian Institute of Hydrology, Meteorology and Environmental Studies (IDEAM for its acronym in Spanish), which contains daily data on rainfall and temperature for more than 2,000 weather stations in the country, and data from PILA, which contains the universe of the mandatory monthly contributions to the social security system of all formal workers in the country. We combine both sources of data to create a rich and novel municipality-level database that allows us to follow more than 80 percent of all rural municipalities in Colombia for the period 2008–2018.

Our main results display a consistent negative effect of excess of rainfall episodes (i.e., above the 90th percent of its historical mean) on formal employment and earnings. On the other hand, the effect of th episodes of lack of rainfall goes in opposite direction. These results are similar to the findings of other studies from countries of the same region (Aragón, Oteiza, and Rud, 2021; Branco and Fres, 2020), and clearly differ from the literature for distant countries like India (Jayachandran, 2006; Nordman, Sharma, and Sunder, 2021). However, we find that lack of precipitation is related with increases in food prices at wholesale centrals, showing evidence that these episodes can be related as negative productivity shocks, since the scarcity of water could induce agricultural producers to use more labor to produce as much as possible.[1].

We also study to what extent the effects of precipitation shocks on the formal rural labor market vary by the differences of input requirements. Our regression estimates display heterogeneous effects by crops. Additionally, we analyze whether the adoption of irrigation technologies could counteract lack of rain shocks as a potential mechanism that could drive our results. We do not find differences between municipalities with high incidence of irriga-

[1] We also find that excessive precipitation is related with higher food prices, but the estimated parameters are not always statistically significant

tion systems relative to those with low incidence. Lack of quality and maintenance of these systems in Colombia could explain these results.

This paper aims to contribute to the literature on short-term responses to climate change in countries. located in Latin America, given that most of the literature is centered in Southeast Asia (Kochar, 1999; Mueller and Osgood, 2009; Loayza et al., 2012; Jessoe, Manning, and Taylor, 2018; Quinones, 2018; Brey and Hertweck, 2019; Burzyński et al., 2019; Maitra and Tagat, 2019) as we study how one of the mitigation mechanisms available to producers, such as quantity of employment hired, responds to unexpected productivity shocks due to changes in rain patterns This paper also adds to the existing literature on informality and labor market regulation in developing countries as in Almeida and Carneiro (2012), Meghir, Narita, and Robin (2015), Ulyssea and Ponczek (2018), and Ulyssea (2020).

The paper proceeds as follows. Section 2 contains the background and data. Section 3 presents the empirical strategy; section 4 presents the results and section 5 looks at heterogeneous effects by crop type and irrigation systems. The section 6 studies rainfall shocks as a productivity shock and section 7 presents some final remarks.

2 Background and Data

In this section, we provide a brief description of the regulation that defines labor formality in Colombia. Then, we discuss some theoretical aspects of the effects of agricultural productivity shocks on the (formal and informal) labor market. Then, we characterize the most important rainfall patterns in Colombia. Last, but not least, we describe the data used in this paper.

2.1 Labor Regulation in Colombia

There are different definitions of formality that depend on the available data and labor regulation of each country. In our case, we will use a legalistic definition based in the Colombian Labor Code that allows us to measure formality in a more strict way than traditional measures such as size of the firm.[2] A worker is classified as formal in two cases. If the worker is an employee, then both the employee and the employer must make monthly mandatory contributions to health care and pensions. Every month, the employee contributes 8 percent of her monthly wage for social security (4 percent to each health care and pensions accounts), while the employer contributes 8.5 percent to the worker's health care account and 12 percent to the pensions account using her monthly wage as the tax base. If the worker is self-employed or independent, then she must pay the full social security contributions by herself (12 percent of her earnings go to health contributions and 16 percent of her earnings go to pensions), but on a reduced tax base equivalent of 40% of the monthly earnings of the worker. In the agricultural labor market, day-laborers are still common and they should also comply with the labor law as if they were self-employed or independent workers.

In the case of a dependent working relationship, the employer must also comply with other regulations mandated by the Labor Code such as not paying wages below the national minimum wage, severance payment, once a year paid vacation time, end-of-the-year bonus, among others.Overall, formal employment is costly in monetary terms, but also in time as hiring a formal worker requires some paper-work that must be done by the employer of by the worker if she is self-employed that is time-consuming. It is important to point out that there is not such a thing as a general unemployment insurance in Colombia when workers

[2]For documents using contributions to social security as definition of informality, see: Pratap and Quintin (2006) and Bobba, Flabbi, and Levy (2018). For papers using firm size as a measure of informality, see: Tannuri-Pianto et al. (2004). For papers using a legalistic measure of informality, see: Almeida and Carneiro (2012), Meghir, Narita, and Robin (2015), and Ulyssea and Ponczek (2018).

are laid off. Formal workers are entitled to a “severance package”, but informal workers do not receive any form of monetary or non-monetary payments when they lose their jobs.

2.2 Conceptual Framework

The production function f has the following properties: f is increasing in each input, but all the inputs exhibit diminishing returns and a diminishing marginal rate of substitution, as all the inputs are necessary for production. This implies that if W=0 or L=0, there is no production.

Under this framework, a rain shock acts as a productivity shock as it directly impacts the availability of the input W. Thus, when there is an excess rain shock, W is readily available, then the producer might substitute some labor L for W, as the cost of water goes down. And when there are shocks of lack of rain, as $W << W^*$, then the producer might hire more labor L to compensate for the lack of water.

Given that water is an essential input for production, a producer who does not have access to technology for controlling the amount of available water, such as drainage and irrigation systems, when exposed to an extreme rain shock it would face production losses.

As we are only focusing on rural municipalities, we assume for simplicity purposes that the rural economy is composed of two sectors: agriculture (A), that absorbs more than 50 percent of the workers in rural areas, (according to our data), and Other (O), mostly comprised by mining and small commercial business. Inside each sector, there is a formal and an informal labor market. On average, workers who work in the formal labor market are more skilled than workers in the informal labor market. Household-level data shows that there is a higher proportion of workers with primary school or less working informally than in formal jobs (one third of high-skilled workers -defined as having reached an education level of middle school or higher- work informally and 2/3 of high-skilled workers work formally, based on our definition of formality).[3]

The formal labor market is the one in which workers and their employers—in case they work for someone else—or self-employed individuals have to make contributions to social security and comply with the current labor regulation such as the mandated national minimum wage. Therefore, formal employees cannot earn less than the minimum wage by definition. Nevertheless, informal jobs are very common in rural areas. Moreover, one could expect to find more informal workers than formal ones for several reasons. First, not enough enforcement of labor the regulation in rural areas. Second, the nature and characteristics of agricultural production (e.g., weather uncertainty, lack of credit access, poor road and utilities infrastructure, high non-labor input costs). Last but not least, low reservation wages for most of rural workers. All these factors together make informal jobs more preferred than being unemployed or out of the labor force.

In the formal labor market, the existence of a minimum wage can cause a mismatch between the quantities of formal labor demanded and supplied at both sectors if the minimum wage is binding, acting as a rigidity. More precisely, one could expect that the quantity of formal labor demanded would be less than the quantity of formal labor supplied if the minimum wage is significantly higher than the equilibrium wage. In such scenario, the workers who wanted to get a formal job in one of the two sectors—let us say in sector A—and could not get it, may have incentives to switch to the informal labor market in sector A and accept a lower-paying informal job instead of searching for a job in the formal labor market in sector O, if the formal workers' skills within sector A cannot not be transferable to sector O.

[3] Ulyssea and Ponczek (2018) also finds a similar behavior for Brazil.

What is the role of the informal labor market? As stated by (Ulyssea and Ponczek, 2018), it might work as a buffer to reduce adjustment costs in the labor market due to shocks. As the informal labor market does not need to comply with labor laws, there are no formal written contracts, employers do not face high hiring or firing costs and wages can be adjusted as necessary. Therefore, any effect on employment and wages will depend on the degree of enforcement to comply with labor regulation.

If an unexpected negative productivity shock takes place in the agricultural sector, it causes a contraction of both the formal and informal labor demand as agricultural production should decrease. As a consequence, formal wages in the agricultural sector would need to adjust but they can only fall up to the minimum wage, causing an increase in unemployment, while in the informal labor market the new equilibrium wage will be determined by the intersection of the shifted labor demand and the labor supply curve that remains unchanged. Nevertheless, as stated by **?**, informal employers might reduce wages only if weather events (that lead to negative productivity shocks) are sufficiently big. Otherwise, they rather prefer to keep wages as in the previous period, generating a labor supply excess. Therefore, a negative productivity shock will decrease employment in the—formal and informal—agricultural sector, with subsequent falls in wages, depending on the size of the shock and the level of enforcement to fulfill social security laws.

As displayed by Figure 1, the negative productivity shock does not only have effects on the agricultural sector, but might have some impacts on the non-agricultural sector. First, the fall of agricultural production might induce a decrease on the demand of non-agricultural good and services from the latter, generating a contraction of the demand on the non-agricultural sector. But, at the same time, some laid off agricultural workers will search for jobs on the other sector, moving forward the supply curve. As a consequence, the formal and informal non-agricultural sector will experience a fall in jobs and wages. The magnitudes of these movements depend of the ridigities that exist inside this sector.

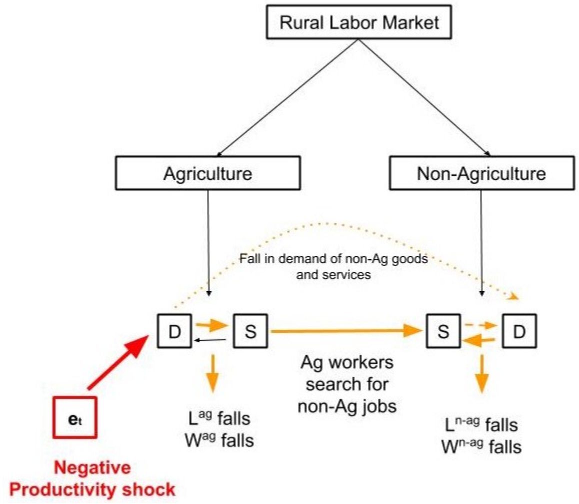


Figure 1: The Effects of a Negative Productivity Shock in the Agricultural Sector

On the other hand, a positive productivity shock in the agricultural sector would shift to the right the labor demand curve, for both formal and informal workers in this sector, if there are no short-term changes in labor supply. But the effect on wages is ambiguous: if the minimum wage is binding in the formal labor market before the shock, then the effect on formal wages would be zero if the new equilibrium wage is still below the minimum wage or it could be positive if the new equilibrium wage is above the minimum wage. However, if the minimum wage was not binding, then the effect would be positive. In the informal labor market, both wages and the quantity of labor demanded are expected to increase. In the aggregate, the magnitude of the effect on wages and total employment depends on the elasticity of the demand curve and if the minimum wage was binding or not. But there might be an effect on the non-agricultural sector, as the positive productivity shock in agriculture should generate an increase in the demand of good and services on the other sector. Therefore, one can expect a rise in the demand of formal and informal labor in the non-agricultural sector. The effect on wages will depend on the same conditions of the agricultural sector (e.g., a binding minimum wage). Figure 2 displays this situation.

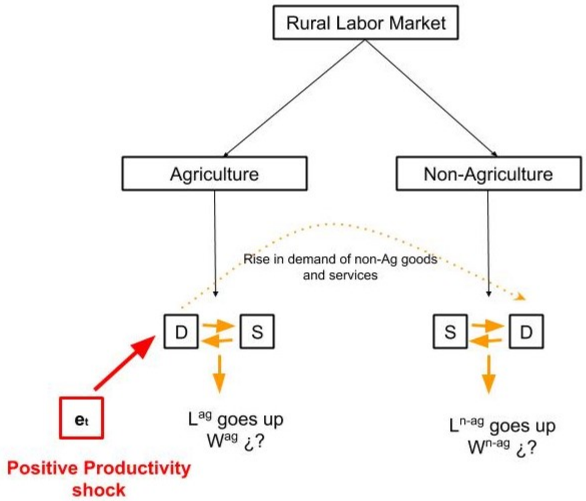


Figure 2: The Effects of a Negative Productivity Shock in the Agricultural Sector

2.3 Characterizing Rainfall Patterns in Colombia

According to the national meteorology authorities, Colombia is one of the most pluviometric-diverse nations in the world.[4] Being located near the Equator, its climate and weather characteristics resemble a tropical country, where temperature changes according to the altitude (i.e., no significant seasonal changes), and precipitation is the only event that really varies across time and location.[5]

The Colombian territory can be divided into five main groups regarding the intensity of precipitation across time. The Caribbean region, located at the north side of the country, is characterized of having two precipitation zones. The northern plains are generally arid. For this area, yearly average precipitation oscillates between 300 and 600mm.[6] The southern area of this region is known from being more humid and rainy due to the confluence of several main rivers. Yearly average precipitation rounds between 1,800 and 2,000mm. The Caribbean region experiences two well-defined rainy seasons throughout the year: the first

[4] http://atlas.ideam.gov.co/cclimatologicas/info/lluviamen.html, consulted on April 28, 2020.
[5] https://www.britannica.com/place/Colombia, accessed on April 28, 2020
[6] One inch of rainfall represents 25mm.

one takes place between the months of April and June, while the second period occurs and between September and December.

The Andean region, situated across the main lands of the Andes range, the annual average intensity of rainfall varies between 2,000 and 4,000mm. The difference in precipitation level within the region slightly varies by latitude. The driest season takes place during mid-year for the southern area, whereas for the northern portion of this region the period with the lowest precipitation levels occurs during the months of December, January, and February. The Orinoquia region, located to the east of the Andes range, experience greater variation in precipitation across its area (between 1,500 and 6,000mm). Rainfall seasons are clearly defined: the rainiest period is the longest and takes place between late-March and November.

The Amazon and Pacific regions are the most exposed to longer and more intensive periods of precipitation. As in the Orinoquia, the Amazon regions experiences the wettest season between the months of April and November, with a yearly average precipitation that oscillates between 3,000 and 4,500mm. On the other hand, the Pacific region is considered as one of the rainiest areas in the world. Yearly average precipitation lies between 8,000 and 10,000mm, and it is harder to identify clear seasonal patterns in rainfall.

2.4 Data

We use two different sources of data. Regarding weather, our data come from the Colombian Institute of Hydrology, Meteorology and Environmental Studies (IDEAM for its acronym in Spanish), including information about rainfall and temperatures for more than 2,000 weather stations in the country. With respect to employment and wages, our data come from the Integrated Register of Social Security Contributions—PILA for its acronym in Spanish, which contains the universe of monthly mandatory contributions to the social security system of all formal workers in the country. Our time period of interest spans from 2008 to 2018. Merging the weather data with PILA generates an unbalanced panel that comprises 524 municipalities in rural areas, as displayed by Figure 3.

2.4.1 Weather Data

We use administrative records from IDEAM, which includes monthly information about total precipitation (in millimeters), number of days with rain, as well as the maximum amount of rainfall in a day of the current month. The IDEAM has collected weather data on rainfall and temperatures for $2,726$ stations since year 1900. It is important to remark that the number of stations has not been constant throughout the years: some have either been closed, moved to another location, or some new stations have been installed.

Our main weather measures correspond to a set of indicator variables equal to one whether the observed monthly amount of precipitation is at or above the 90th percentile, or at or below the 10th percentile of the historical distribution, for any given municipality. Our final database generates an unbalanced panel that comprises 516 municipalities in rural areas (more than 80 percent of total rural municipalities in Colombia).

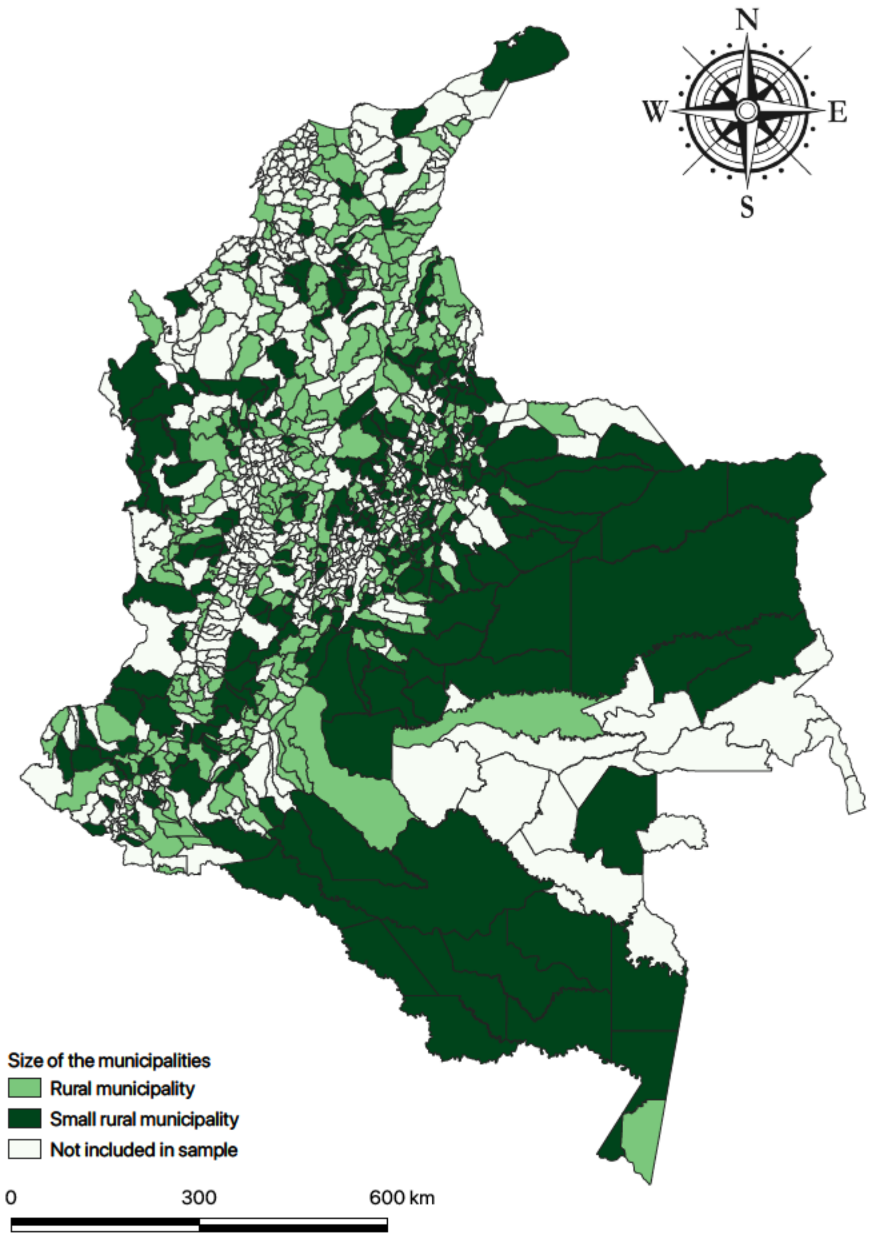


Figure 3: Municipalities Included in the PILA-weather merged data set

We estimate historical distributions of precipitation by using data for municipality i at month m for the last 30 years. This approach helps us to account for seasonality. For municipalities with more than one weather station, we compute the average rainfall from all stations at a given point in time t. To estimate monthly weather shocks between July 2008 and June 2018, we use historical data since 1979. For this period, we have rainfall data collected by $2,423$ unique stations. After accounting for re-locations, closures, and new installations, we have an average of $1,796$ stations per month–year. As reported by Table 1, larger municipalities by population are more likely to have more weather stations than their smaller counterparts. In Figure 4, we display the distribution of rainfall shocks across time. For this figure, we can observe that during our period of study (July 2008–June 2018), Colombia experienced more and longer episodes from La Niña than El Niño and, likewise, more monthly rainfall events when precipitation was above the 90th percentile

Table 1: Distribution of Weather Stations by Type of Municipality, 1979–2016

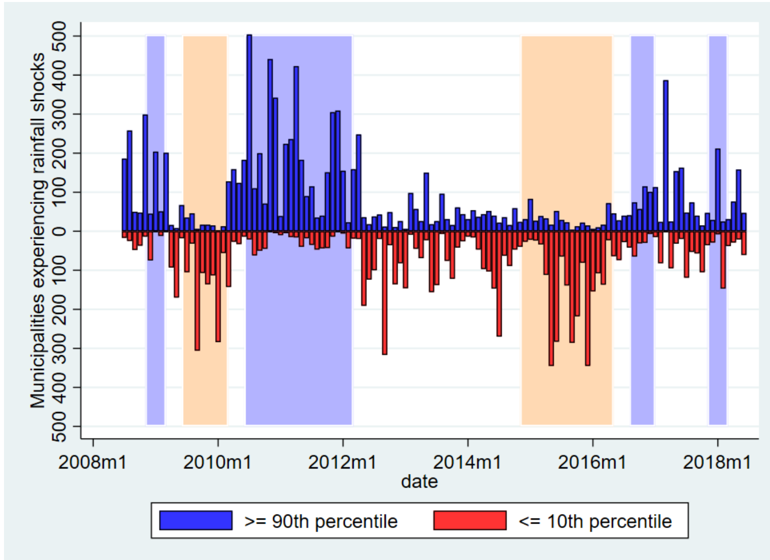
Municipal category	No. of Stations	No. of Municipalities	Ratio
Cities/conglomerates	306	83	3.69
Intermediate	430	209	2.06
Rural	568	269	2.11
Rural (disperse)	492	238	2.06

2.4.2 Employment Data

The PILA dataset includes information on pre-tax earnings, number of days worked, payroll taxes, and some demographic characteristics for the universe of formal workers in Colombia (i.e., those who pay contributions to health and pension) since July 2008. On average, there are approximately 8 million observations per month including urban workers, which account for the majority of formal employment in the country.

Using these records, we estimate the total monthly number of formal employment and the

Figure 4: Distribution of Rainfall Shocks, El Niño and La Niña Episodes, 2008–2018



Light blue areas corresponds to La Niña episodes, whereas light red areas refers to El Niño episodes.
Source: Colombian Institute of Hydrology, Meteorology and Environmental Studies

average earnings for each municipality in our final sample. As Table 2 displays, the number of formal workers in rural areas has more than doubled between 2008 and 2018. However, formal employment in rural municipalities corresponds to a very small share of total formal employment in Colombia (around 15 percent), as stated by Otero-Cortés (2019). On average, formal rural workers earn 1.8 times the monthly minimum wage.

Although the Colombian Household Survey, GEIH, is the main tool for studying the Colombian labor market and its characteristics, for our estimations we cannot use this survey because its sampling design does not allow us to follow a significant group of rural municipalities over time. But as the GEIH is statistically representative of the rural areas of the country as a whole, we can get a picture of the rural labor market from it.

Between 2008-2018, there were, on average, 4.5 million people working in the rural areas of Colombia. The labor force participation rate was, on average, 58 percent, and the unemployment rate 6.5 percent, which is significantly lower (5 p.p.) than the one in the

Table 2: Descriptive Statistics, Formal Rural Workers

	Employment		Wages		Share
Year	Mean	Std. dev.	Mean	Std. dev.	min. wage
2008	214,018.83	27,555.63	829,701.50	47,137.81	179.78
2009	258,431.75	23,840.34	866,770.75	46,971.92	177.89
2010	305,534.25	28,199.26	917,147.13	47,600.14	187.35
2011	329,577.92	41,356.11	932,943.13	42,356.89	190.08
2012	367,837.50	39,873.25	971,097.19	52,183.47	191.53
2013	384,680.33	40,584.73	990,135.88	55,676.56	191.33
2014	435,367.08	35,159.39	975,805.13	29,746.52	187.03
2015	455,007.92	32,949.53	953,142.81	30,251.50	186.46
2016	438,907.75	55,209.53	930,881.50	67,019.95	179.99
2017	496,506.42	56,640.20	953,303.56	87,463.29	179.30
2018	530,476.33	39,864.40	987,332.44	71,681.82	179.68

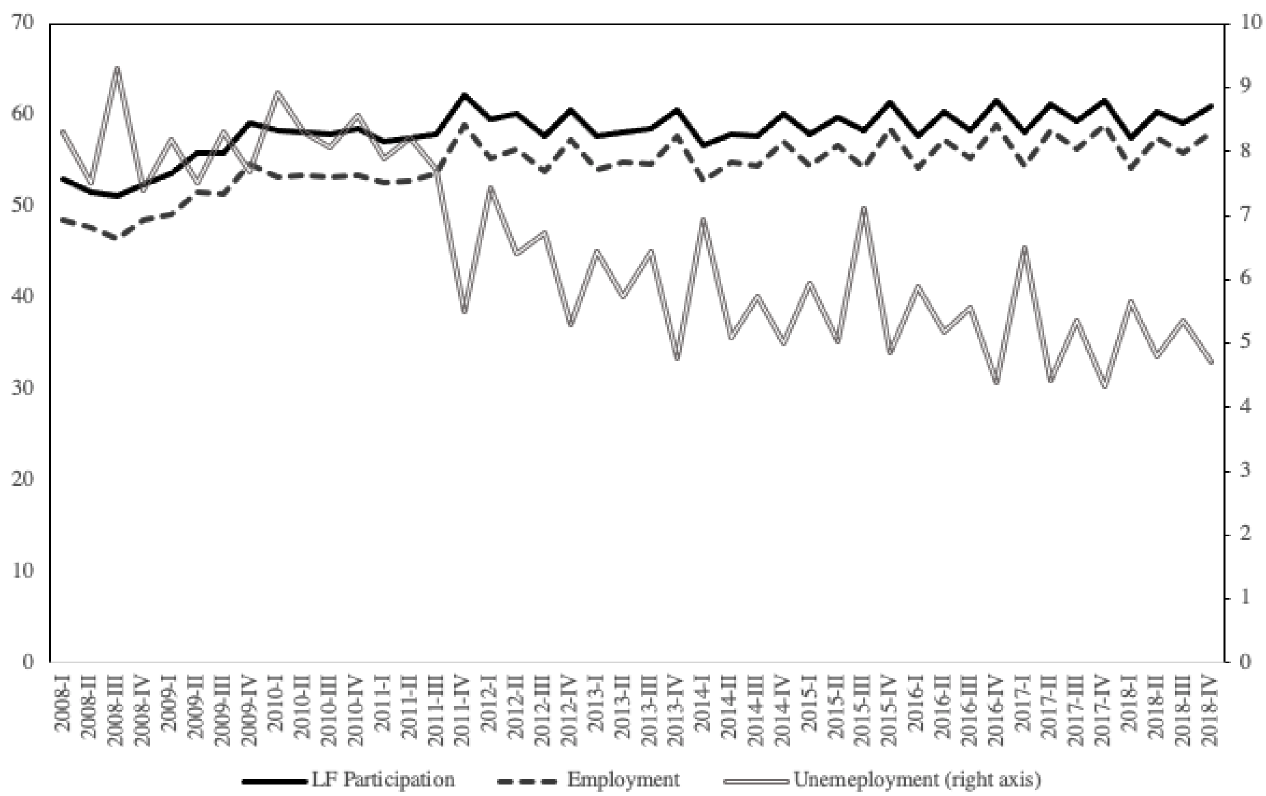
For both employment and wages, we display the monthly average value for each year. Wages are reported in 2008 constant prices. Source: PILA and IDEAM.

urban areas of Colombia. Labor informality is highly prevalent in rural areas and sits at about 88 percent the total employment based on our definition of formality using pension contributions.

The main source of job opportunities in rural areas comes from the agricultural sector (63 percent of the working population are there), followed by the services and retail sector that hires, on average, 12 percent of the working population. We also find that pensions and health contributions, although low, they have significantly increased around 50% throughout the period of interest.

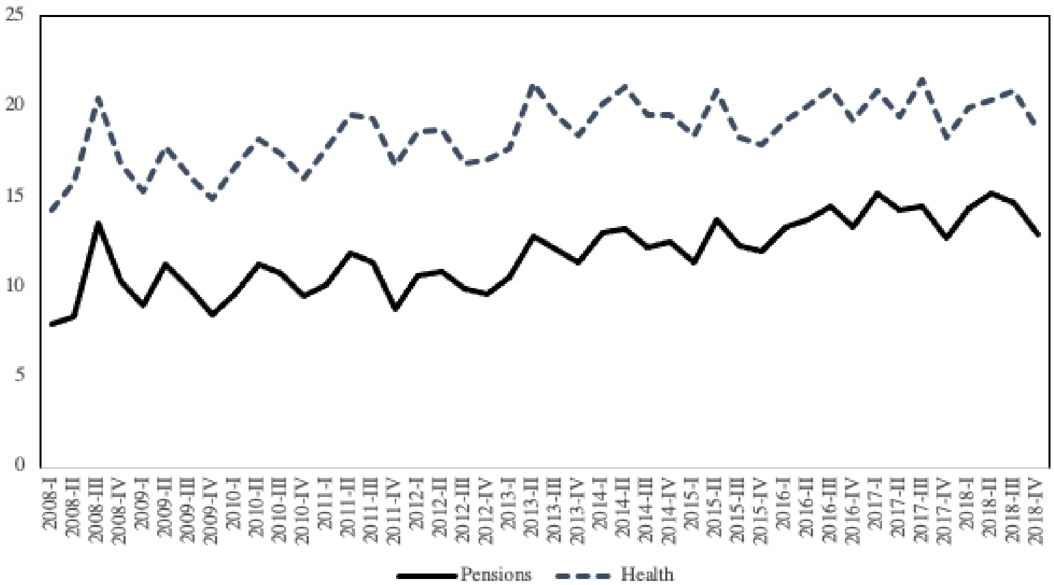
Earnings in the rural labor market are low when compared to the national minimum wage. Self-employed workers, which represent around 50% of the workers, have monthly earnings that are, on average, half a minimum wage. Public sector employees have the highest earnings, and also the fastest growing earnings, followed by employees from private companies. Day-laborers have earnings slightly below the minimum wage. Table 3 shows average monthly pre-tax earnings for formal and informal workers separately. Based on this,

Figure 5: Labor Force Indicators for Colombia, 2008–2018



Source: Colombian GEIH

Figure 6: Share of Rural Workers Contributing to Social Security in Colombia, 2008–2018



Source: Colombian GEIH

we find that formal rural workers have earnings that are above the established minimum wage, on average, but informal workers (this group represents more than 80% of the working population in rural areas) have consistently lower earnings.

Table 3: Average monthly pre-tax earnings for formal workers and informal workers (in constant prices), 2008–2018

	Formal workers		Informal workers		Total	
	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
2008	757.933	669.724	262.797	392.284	312.611	447.866
2009	797.725	2.256.703	262.136	322.294	313.963	733.089
2010	800.917	1.140.094	262.568	336.241	317.622	495.633
2011	814.054	727.824	265.756	335.282	323.316	419.797
2012	843.922	1.720.599	265.269	357.618	324.983	640.198
2013	840.509	552.643	273.757	320.563	342.802	394.180
2014	859.072	706.781	275.995	324.328	353.141	431.323
2015	834.353	637.967	274.261	309.935	345.900	403.319
2016	838.278	675.129	281.141	313.341	360.030	418.681
2017	847.503	705.388	286.901	347.986	368.817	449.352
2018	826.195	907.629	280.764	303.888	360.747	471.885

Source: Colombian GEIH

3 Empirical Strategy

We follow Jayachandran (2006) by relying on municipality and month fixed-effect models to estimate the impact of weather shocks on formal employment and earnings. Our basic model accounts for the variation on the outcomes of interest and the weather measures described in Section 2.4.1 (total amount of precipitation, niño and niña indicators, and rain shocks as well):

$$log(Y_{imt}) = \beta_0 + \beta_1 W^{+}_{imt} + \beta_2 W^{-}_{imt} + \beta_3 W^{+}_{imt-1} + \beta_4 W^{-}_{imt-1} + a_i + b_m + u_{imt} \quad (1)$$

where Y_{it} corresponds to the outcome of interest (total formal employment or average wages) in logarithms for municipality i in month m of year t, W^{+}_{imt}, W^{-}_{imt-1}, W^{-}_{imt}, and W^{-}_{imt-1} account for current and lagged realizations of our measures of rainfall of interest, respectively.[7]; a_i and b_m are the municipality and month fixed effects, respectively, and u_{imt} is a zero-mean error. From this model, the parameters of interest are β_1 to β_4, since they intend to capture the effect of current and past weather shocks on changes in formal unemployment or wages from their averages.

To claim a causal effect from our estimates, we need to ensure our explanatory variables are plausibly exogenous (i.e., no presence of unobserved heterogeneity, measurement error, or reverse causality). Regarding unobserved heterogeneity, time-invariant location-specific characteristics can also affect the impact of rain shocks on formal employment. As explained in Section 2.3, the Colombian geography is heterogeneous, embracing different altitudes, as well as varied precipitation and temperature zones. Consequently, either episodes of rainfall above or below historical means are expected to have a different effect depending on the

[7]The inclusion of past realizations of precipitation events intend to account for the persistence of those episodes on current employment.

affected area. Therefore, we include municipality-level fixed effects to account for location–based heterogeneity. Likewise, we also include month fixed effects to address unobserved time-variant characteristics. With respect to reverse causality, we do not expect it to be an issue. Our labor outcomes—formal employment and earnings—should not affect climate shocks.

Our main concern comes from measurement error. Several aspects could exacerbate this issue. Although climate and formal employment data are administrative records, they are not entirely exempt from being wrongly measured. The presence of measurement error in the dependent variable implies that our regression estimates would remain unbiased, but with larger standard errors. To correct for that issue, we estimate our regression models with municipality-level clustered standard errors. Regarding weather, it is likely to expect that our data on precipitation is more accurate for larger municipalities, because they might count with more than one weather station, and they should be better equipped and maintained in comparison with those from smaller towns. As explained in Section 2.4, we count, on average, with more than two weather stations by municipality, for both rural and rural disperse categories. That allows us averaging precipitation data over time for most municipalities, helping us to increase accuracy on our explanatory variables by reducing the reliability of our measures on just one observation, helping us to significantly reduce measurement error.

4 The effects on the Formal Labor Market

We begin with reporting the regression estimates of the effects of current and lagged values of precipitation (in inches) on formal rural employment and earnings.[8] The results from Table 4 shows that a 1-inch increase in monthly rainfall reduces formal rural employment between

[8] 1 inch = 25.4 mm

1.02 and 1.24 percent points (panel a, columns 1 and 2). The positive and statistically significant estimates of the squared term indicate potential non-linearities of such behavior. Additionally, we observe the negative effect of rainfall on employment presents some persistence, as displayed by the regression estimates of the lagged values of precipitation. As expected, this impact is greater for the agricultural (panel a, columns 3 and 4) sector relative to the rest (panel a, columns 5 and 6): a 1-inch increase of monthly rainfall leads to a fall in formal agricultural employment between 1.34 and 1.75 percent. For non-agricultural sectors, such fall lies between 1.0 and 1.21 percent.

With respect to earnings, the regressions estimates from panel b of Table 4 also reveal a negative relationship with changes in precipitation. On average, a 1-inch increase in monthly precipitation leads to a decrease in earnings between 0.34 and 0.37 percent points. The greatest fall takes place at the non-agricultural sector (-0.36 to -0.39 percent points). These estimates reflect that earnings are less responsive in the formal agricultural sector with respect to the non-agricultural sector.

To identify non-linearities on the impact of precipitation on the formal rural labor market, we estimate Equation 1 using monthly indicators of rainfall above the 90th percentile (hereafter, AA shocks) and below the 10th percentile (hereafter, BA shocks) from its historical mean. Under this approach, we are also able to identify the effects of episodes of lack of rainfall, which should also affect agricultural production. Column 1 from Table 5 displays asymmetries on the effects of rainfall shocks on total formal rural employment. According to the results, current and lagged AA episodes lead to a decrease in total formal employment of 9.54 and 5.43 percent points, respectively. The effects of BA shocks is smaller in magnitude and goes in opposite direction: current and lagged episodes correspondingly increase employment in 3.24 and 2.80 percent points. Both AA and BA episodes display signs of persistence. Regarding earnings, column 1 of Table 6 shows that AA and BA shocks affect formal earnings in rural areas in the same directions as with employment.

Columns 3 and 5 of Table 5 display the regression estimates by sectors. As expected, the average effect of both AA and BA shocks on formal employment are greater for the agricultural sector (-13.41 and 6.39 percent points, respectively) with respect to the other sectors (-9.23 and 3.07 percent points, respectively). The persistence of these weather events is greater for the latter sector, as the regression estimates of the lagged terms display. With respect to earnings (columns 3 and 5 from Table 6), the fall due to excessive precipitation is greater for the non-agricultural sector (-3.07 percent points) compared with the agricultural sector (-0.89 percent points), whereas the rise in earnings due episodes of lack of rain is statistically significant only in the non-agricultural sector (1.05 percent points).

As a robustness check, Columns 2, 4, and 6 from Tables 5 and 6 display the regression estimates of Equation 1, but allowing for smaller bins of the historic distribution of monthly precipitation by municipality. The estimated coefficients for AA shocks show a more negative relationship between these type of episodes and formal employment and earnings as well, as the severity of these shocks increases. On the other hand, the regression estimates for BA shocks show a negative relationship with employment and earnings, but for those shocks that fall at or below the 5th percentile of the historical rainfall distribution the effect is not clear. As in columns 3 and 5, the effect of both AA and BA shocks is greater on employment at the agricultural sector relative to the other sectors, whereas the greatest impacts of precipitation shocks on earnings take places at the non-agricultural sector. Additionally, we observe persistence of lagged precipitation shocks on the outcomes of interest.

Table 4: The effect of monthly precipitation in the formal rural labor market

(a) Dependent variable: asinh(employment)

	Total		Agricultural		Nonagricultural	
	(1)	(2)	(3)	(4)	(5)	(6)
Monthly Precipitation (inches)	-0.0124***	-0.0102***	-0.0175***	-0.0134***	-0.0121***	-0.0100***
	(0.0013)	(0.0011)	(0.0028)	(0.0025)	(0.0013)	(0.0011)
Monthly Precipitation^2	0.0002***	0.0002***	0.0003***	0.0003***	0.0002***	0.0002***
	(0.0000)	(0.0000)	(0.0001)	(0.0001)	(0.0000)	(0.0000)
L.Monthly Precipitation (inches)		-0.0019***		-0.0068***		-0.0016***
		(0.0006)		(0.0012)		(0.0006)
Observations	59,167	58,295	59,167	58,295	59,167	58,295
Municipalities	516	515	516	515	516	515

(b) Dependent variable: log(wages)

	Total		Agricultural		Nonagricultural	
	(1)	(2)	(3)	(4)	(5)	(6)
Monthly Precipitation (inches)	-0.0037***	-0.0034***	-0.0016**	-0.0012*	-0.0039***	-0.0036***
	(0.0005)	(0.0005)	(0.0007)	(0.0007)	(0.0005)	(0.0005)
Monthly Precipitation^2	0.0001***	0.0001***	0.0000	0.0000	0.0001***	0.0001***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
L.Monthly Precipitation (inches)		-0.0001		-0.0004		-0.0001
		(0.0002)		(0.0003)		(0.0002)
Observations	59,167	58,295	43,008	42,479	59,167	58,295
Municipalities	516	515	512	511	516	515

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table 5: The effect of rainfall shocks on formal rural employment

	Total		Agricultural		Nonagricultural	
	(1)	(2)	(3)	(4)	(5)	(6)
I [Precipitation] ≥ 90th percentile	-0.0954***		-0.1341***		-0.0923***	
	(0.0095)		(0.0211)		(0.0094)	
I [Precipitation] ≤ 10th percentile	0.0324***		0.0639***		0.0307***	
	(0.0081)		(0.0178)		(0.0081)	
L.I [Precipitation] ≥ 90th percentile	-0.0543***		-0.1492***		-0.0485***	
	(0.0092)		(0.0208)		(0.0092)	
L.I [Precipitation] ≤ 10th percentile	0.0280***		0.0653***		0.0246***	
	(0.0079)		(0.0180)		(0.0079)	
I [Precipitation] ∈ 80th-90th percentile		-0.0583***		-0.0807***		-0.0553***
		(0.0091)		(0.0182)		(0.0092)
I [Precipitation] ∈ 90th-95th percentile		-0.0781***		-0.1079***		-0.0771***
		(0.0113)		(0.0258)		(0.0113)
I [Precipitation] ≥ 95th percentile		-0.1173***		-0.1625***		-0.1120***
		(0.0127)		(0.0278)		(0.0127)
I [Precipitation] ∈ 10th-20th percentile		0.0286***		0.0288*		0.0278***
		(0.0081)		(0.0168)		(0.0083)
I [Precipitation] ∈ 5th-10th percentile		0.0386***		0.0743***		0.0374***
		(0.0105)		(0.0242)		(0.0106)
I [Precipitation] ≤ 5th percentile		0.0180		0.0356		0.0163
		(0.0110)		(0.0226)		(0.0111)
L.I [Precipitation] ∈ 80th-90th percentile		-0.0230**		-0.0863***		-0.0198**
		(0.0092)		(0.0190)		(0.0093)
L.I [Precipitation] ∈ 90th-95th percentile		-0.0548***		-0.1234***		-0.0519***
		(0.0120)		(0.0250)		(0.0124)
L.I [Precipitation] ≥ 95th percentile		-0.0491***		-0.1814***		-0.0403***
		(0.0125)		(0.0279)		(0.0124)
L.I [Precipitation] ∈ 10th-20th percentile		0.0189**		0.0269*		0.0189**
		(0.0080)		(0.0161)		(0.0080)
L.I [Precipitation] ∈ 5th-10th percentile		0.0345***		0.0755***		0.0287**
		(0.0112)		(0.0239)		(0.0113)
L.I [Precipitation] ≤ 5th percentile		0.0154		0.0348		0.0155
		(0.0106)		(0.0234)		(0.0108)
Observations	58,295	58,295	58,295	58,295	58,295	58,295
Municipalities	515	515	515	515	515	515

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table 6: The effect of rainfall shocks on formal rural earnings

	Total		Agricultural		Nonagricultural	
	(1)	(2)	(3)	(4)	(5)	(6)
I [Precipitation] ≥ 90th percentile	-0.0281***		-0.0089*		-0.0307***	
	(0.0037)		(0.0046)		(0.0037)	
I [Precipitation] ≤ 10th percentile	0.0101***		0.0010		0.0105***	
	(0.0028)		(0.0047)		(0.0029)	
L.I [Precipitation] ≥ 90th percentile	-0.0114***		-0.0104**		-0.0135***	
	(0.0035)		(0.0048)		(0.0036)	
L.I [Precipitation] ≤ 10th percentile	0.0133***		-0.0032		0.0147***	
	(0.0031)		(0.0045)		(0.0032)	
I [Precipitation] ∈ 80th-90th percentile		-0.0206***		-0.0085**		-0.0223***
		(0.0032)		(0.0038)		(0.0033)
I [Precipitation] ∈ 90th-95th percentile		-0.0239***		-0.0093*		-0.0257***
		(0.0048)		(0.0053)		(0.0048)
I [Precipitation] ≥ 95th percentile		-0.0351***		-0.0079		-0.0390***
		(0.0049)		(0.0062)		(0.0050)
I [Precipitation] ∈ 10th-20th percentile		0.0067**		0.0078*		0.0052
		(0.0031)		(0.0043)		(0.0032)
I [Precipitation] ∈ 5th-10th percentile		0.0088**		0.0074		0.0090**
		(0.0039)		(0.0058)		(0.0039)
I [Precipitation] ≤ 5th percentile		0.0078**		-0.0064		0.0075**
		(0.0037)		(0.0072)		(0.0038)
L.I [Precipitation] ∈ 80th-90th percentile		-0.0078***		-0.0087**		-0.0099***
		(0.0030)		(0.0040)		(0.0031)
L.I [Precipitation] ∈ 90th-95th percentile		-0.0135***		-0.0098*		-0.0151***
		(0.0046)		(0.0053)		(0.0048)
L.I [Precipitation] ≥ 95th percentile		-0.0089*		-0.0111*		-0.0120**
		(0.0046)		(0.0060)		(0.0047)
L.I [Precipitation] ∈ 10th-20th percentile		0.0030		0.0065		0.0028
		(0.0030)		(0.0041)		(0.0030)
L.I [Precipitation] ∈ 5th-10th percentile		0.0114***		0.0021		0.0124***
		(0.0040)		(0.0049)		(0.0040)
L.I [Precipitation] ≤ 5th percentile		0.0125***		-0.0099		0.0137***
		(0.0044)		(0.0067)		(0.0045)
Observations	58,295	58,295	42,479	42,479	58,295	58,295
Municipalities	515	515	511	511	515	515

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

In summary, the estimates from Tables 4 to 6 show that monthly episodes of excessive rainfall have a negative effect on the formal rural labor market. Total employment falls as these events become more severe, especially at the agricultural sector. With respect to earnings, such decrease takes place with more strength for non-agricultural jobs. With respect to episodes of lack of rain, the effect goes in opposite direction. These results are very similar to the findings of Aragón, Oteiza, and Rud (2021) and Branco and Fres (2020) for subsisting farmers in neighboring countries like Peru and Brazil, respectively. They find that negative rainfall shocks (i.e., episodes with lack of precipitation) increase the probability of having a secondary job, especially in non-agricultural sectors. In our case, we cannot estimate the effects on the informal labor market since there is no data that allow us to construct informal employment series for municipalities in rural locations. But, we hypothesize that the effects on the informal rural labor markets could be greater since this market allows for more flexibility in terms of hiring and job termination than the formal labor market, which is tied to labor regulation.

Additionally, our regression estimates can be reflecting formal farmer's input choices on labor and water. As rainfall increases, it becomes more available and, thus, relatively cheaper than labor (as we explained in Section 2.2). On the contrary, when rainfall becomes more scarce, farmers have to rely more on labor to produce as much as possible. These results make sense in the context of a country like Colombia, in which many farms do not count with proper irrigation systems. In the next section, we present evidence of heterogeneous effects by different types of crops and access to irrigation system.

5 Addressing Heterogeneous Effects

The effects of precipitation shocks on formal employment and earnings could also vary by crops. Each crop can have its own input requirements and, thus, the impact of extreme changes in weather can affect in different ways. Based on information from the Colombian Agricultural Municipal Evaluations of 2007 (hereafter EVA), we identify the most relevant crops in the country in terms of area sown. According to the data, maize, potato, rice, yucca—as non-perennial crops, and coffee—as a perennial crop—are the ones with the largest extensions of area sown in Colombia. Thus, we construct several subsamples that group municipalities by the most farmed crop. Figure 7 displays a Colombian map indicating the most relevant crop for the municipalities in our sample.

Tables A1 to A10 of the Appendix display the regression estimates of the effect of municipality-level rainfall shocks for those municipalities we identified as their most farmed crop (in absolute terms) one of the crops listed above. With respect to coffee, we clearly observe a negative effect of AA shocks on employment and earnings. As with the full sample, the impact on employment is greater in agriculture, and the effect on earnings is more important for non-agricultural jobs. For this crop, BA shocks below the 10th percentile seems not to be significant in increasing jobs. We find similar results for maize and yucca-oriented municipalities. In rice-oriented municipalities, we do not find effects on earnings, but there is a lagged effect on employment, especially at the agricultural sector. For municipalities specialized in producing potato, we do not find effects of precipitation shocks on the formal labor market, which is unexpected since this crop is one of the least developed crops in the country in terms of technology.

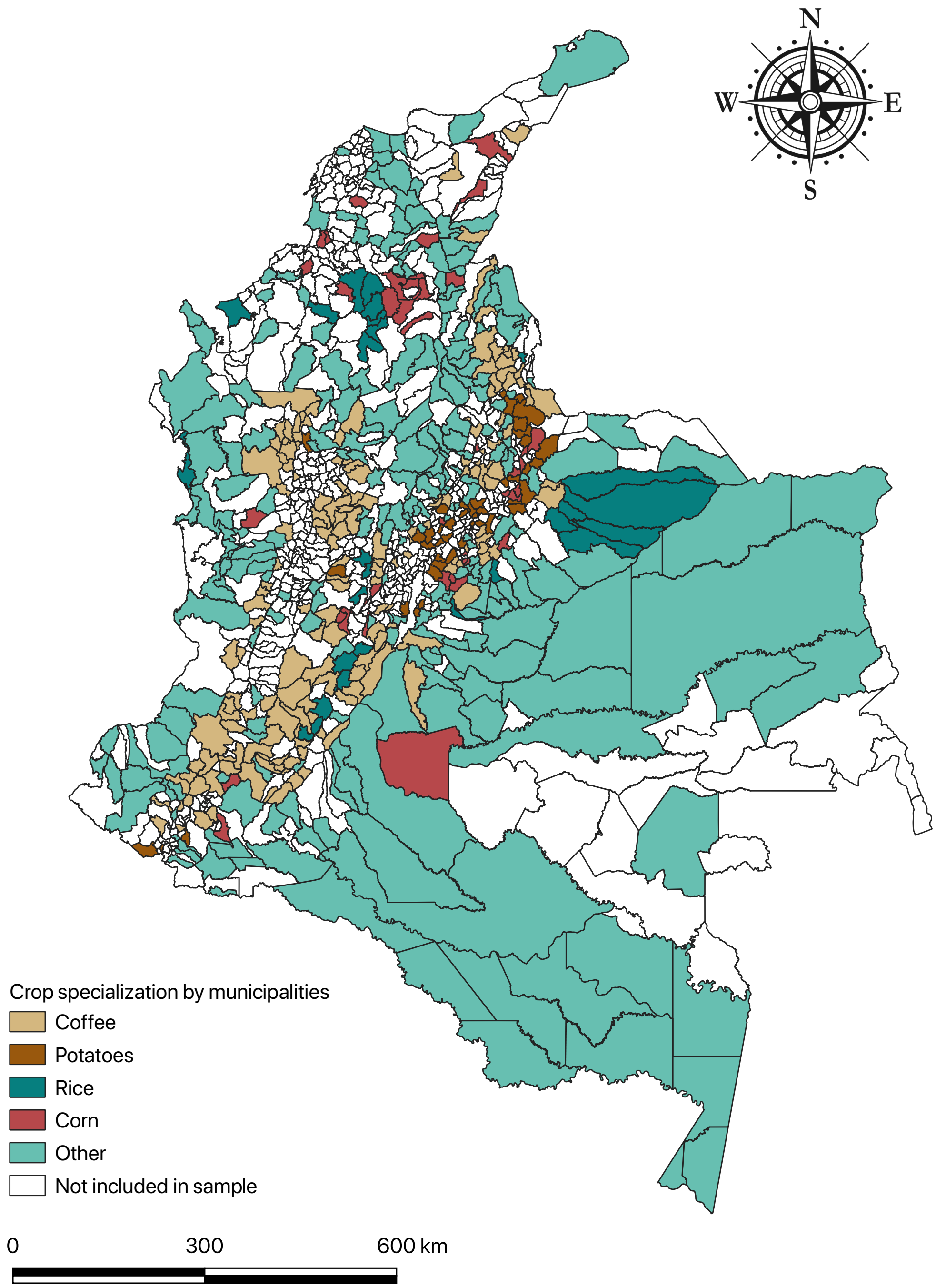


Figure 7: Map of municipalities by crop specialization

The existence of irrigation systems can help farms to mitigate the effects of episodes of little rain or droughts. Using information from the Colombian Agricultural Census of 2013 (hereafter CNA), we identify whether an agricultural production unit (UPA in Spanish) is equipped with irrigation system for agricultural production. Knowing the area sown of each UPA, we calculate the share of total area sown with irrigation system by municipality. A given municipality is categorized as with low incidence of irrigation systems whether that share is less than 50 percent of total area sown. Otherwise, is cataloged as with high incidence.

Tables A11 to A14 display the regression estimates of Equation 1 for the sub-samples of municipalities classified according to the incidence of irrigation systems. The regression estimates show that the effects of BA shocks on agricultural employment is just smaller for municipalities with higher incidence of irrigation systems relative to those with low incidence. This result could reflect inefficiencies on the use of irrigation, due to the quality of the systems in Colombia.

6 Extreme Rainfall Events and Productivity Shocks

So far, we have presented evidence of the effects of monthly rainfall shocks—measured as episodes of excessive or lack of rain with respect to historical data—on formal rural employment and earnings. The regression estimates shows that AA shocks decrease formal employment and earnings, while BA shocks have the contrary effect. These results are consistent with previous findings for other South American countries (Aragón, Oteiza, and Rud, 2021; Branco and Fres, 2020), but differs from the literature for distant countries like India (Jayachandran, 2006; Nordman, Sharma, and Sunder, 2021). The question is whether AA shocks are positive productivity shocks for Colombia, whereas BA socks act like negative productivity shocks.

We do not count with monthly data on agricultural production by municipalities, but we can rely on information on food prices at wholesale centrals beginning November/2012. We expect an inverse relationship between productivity shocks and food prices. Data on prices come from the Colombian Department of Statistics (DANE). These data allow us to identify the origin of each product that is sold at each wholesale central.

We estimate Equation 1 using prices of the most important crop for each municipality (based on the EVA) at the closest wholesale central as the outcome of interest. To identify the closest municipality with a wholesale central that bought the corresponding product, we use two different measures for distance: linear distance between the corresponding centroids and a Google Drive-based distance between these points, to control for differences in topography and road infrastructure conditions. The regression estimates reported in Tables 7 and 8 show that AA shocks are negatively related with food prices, but the regression estimates are only statistically significant for potato. On the other hand, BA shocks increase prices, with the exception of coffee. The greatest impacts of BA shocks come from yucca and potato prices. These results relate lack of precipitation with negative productivity shocks, as these weather episodes increase the use of formal labor and, consequently, raise output prices.

We believe the lack of statistical significance of the majority of the estimated coefficients associated with AA shocks comes from the fact that between November/2012 and June/2018 the number of episodes of excessive rain was much smaller relative to BA shocks, as reflected in Figure 4. We double-checked this situation by re-estimating Equation 1 for the period of time we have data on prices. The regression estimates from Tables A15 and A16 of the Annex show that the effect of AA shocks on formal employment is negative and statistically significant only for the non-agricultural sector. The estimated parameter for the agricultural sector is not significant.

Table 7: The effect of rainfall shocks on prices (based on linear distance from municipality to nearest wholesale center)

	Coffee	Potato	Rice	Maize	Yucca
	(1)	(2)	(3)	(4)	(5)
I [Precipitation] $\geq$ 90th percentile	-0.001	-0.167***	-0.005	-0.012	0.019
	(0.001)	(0.025)	(0.010)	(0.011)	(0.026)
I [Precipitation] $\leq$ 10th percentile	-0.004***	0.069***	0.031***	0.018**	0.070*
	(0.001)	(0.022)	(0.007)	(0.007)	(0.036)
L.I [Precipitation] $\geq$ 90th percentile	0.000	-0.170***	-0.005	-0.011	0.011
	(0.002)	(0.023)	(0.010)	(0.010)	(0.027)
L.I [Precipitation] $\leq$ 10th percentile	-0.002*	0.071***	0.031***	0.012*	0.075**
	(0.001)	(0.024)	(0.008)	(0.007)	(0.034)
Observations	9,764	3,112	1,908	3,803	1,910
Municipalities	151	50	29	58	29

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Colombian Department of Statistics.

Table 8: The effect of rainfall shocks on prices (Google Maps-based distance from municipality to nearest wholesale center)

	Coffee	Potato	Rice	Maize	Yucca
	(1)	(2)	(3)	(4)	(5)
I [Precipitation] $\geq$ 90th percentile	-0.001	-0.161***	-0.005	-0.012	-0.000
	(0.002)	(0.024)	(0.010)	(0.011)	(0.022)
I [Precipitation] $\leq$ 10th percentile	-0.005***	0.058***	0.030***	0.016*	0.070*
	(0.002)	(0.021)	(0.007)	(0.008)	(0.036)
L.I [Precipitation] $\geq$ 90th percentile	0.000	-0.155***	-0.004	-0.011	-0.006
	(0.002)	(0.022)	(0.009)	(0.010)	(0.023)
L.I [Precipitation] $\leq$ 10th percentile	-0.003*	0.053**	0.030***	0.014*	0.079**
	(0.002)	(0.023)	(0.008)	(0.008)	(0.033)
Observations	9,697	3,112	1,908	3,803	1,910
Municipalities	150	50	29	58	29

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Colombian Department of Statistics.

7 Concluding Remarks

This paper addresses the relationship between weather shocks and formal rural employment and earnings in Colombia. We find that municipality-level episodes of monthly rainfall above the 90th percentile of its historical distribution have a negative effect on formal employment that ranges between 9.23 and 13.41 percent points. Regarding earnings, the effect lies between -0.89 and -3.07 percent points. On the other hand, episodes of lack of rainfall increase formal rural employment (between 3.07 and 6.39 percent points) and earnings as well (only at the non-agricultural sector). We also find heterogeneous effects by different types of crops. Additionally, we do not find clear evidence of the incidence of irrigation as a mechanism that could counteract lack of rain shocks, which could be due to poor implementation of these systems in Colombia.

Our results are similar from those found for neighboring countries like Brazil and Peru, and differ from studies for Southeast Asia and India in which excessive rainfall episodes (e.g., monsoon periods) increase rural employment. We consider that such differences could be due to the heterogeneity of geographic, orographic, and pluviometric conditions across countries, which have an incidence in the way that precipitation affects agriculture.

Given our findings, we explore whether precipitation shocks affect agricultural productivity. To achieve this goal, we identify the closest wholesale central in which agricultural producers sells their produce to gather sale prices of these products. We find evidence that episodes of lack of rainfall are related with increases in food prices at wholesale centers, indicating that these events could act like negative productivity shocks because producers have to hire more labor to keep a constant amount of production, which is a different mechanism from what has been displayed by previous literature.

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A.1 Regression estimates by crop orientation

Table A1: The effect of rainfall shocks on formal employment in coffee-oriented municipalities

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.1168***	-0.2086***	-0.1103***
	(0.0145)	(0.0399)	(0.0144)
I [Precipitation] $\leq$ 10th percentile	0.0182	0.0248	0.0203
	(0.0138)	(0.0313)	(0.0139)
L.I [Precipitation] $\geq$ 90th percentile	-0.0843***	-0.2128***	-0.0793***
	(0.0152)	(0.0378)	(0.0154)
L.I [Precipitation] $\leq$ 10th percentile	0.0539***	0.0414	0.0510***
	(0.0132)	(0.0330)	(0.0133)
Observations	17,568	17,568	17,568
Municipalities	156	156	156

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A2: The effect of rainfall shocks on formal earnings in coffee-oriented municipalities

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0250***	-0.0170*	-0.0277***
	(0.0062)	(0.0102)	(0.0063)
I [Precipitation] $\leq$ 10th percentile	0.0071	-0.0075	0.0065
	(0.0052)	(0.0076)	(0.0052)
L.I [Precipitation] $\geq$ 90th percentile	-0.0131*	-0.0104	-0.0158**
	(0.0067)	(0.0105)	(0.0068)
L.I [Precipitation] $\leq$ 10th percentile	0.0214***	-0.0101	0.0229***
	(0.0058)	(0.0075)	(0.0056)
Observations	17,568	12,514	17,568
Municipalities	156	154	156

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A3: The effect of rainfall shocks on formal employment in potato-oriented municipalities

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] ≥ 90th percentile	-0.0462*	0.0092	-0.0465**
	(0.0232)	(0.0625)	(0.0227)
I [Precipitation] ≤ 10th percentile	0.0240	0.0341	0.0223
	(0.0186)	(0.0420)	(0.0192)
L.I [Precipitation] ≥ 90th percentile	0.0064	-0.0310	0.0107
	(0.0245)	(0.0629)	(0.0246)
L.I [Precipitation] ≤ 10th percentile	-0.0281	0.0360	-0.0308
	(0.0190)	(0.0457)	(0.0199)
Observations	5,586	5,586	5,586
Municipalities	51	51	51

* p < 0.1, ** p < 0.05, *** p < 0.01. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A4: The effect of rainfall shocks on formal earnings in potato-oriented municipalities

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] ≥ 90th percentile	-0.0061	0.0063	-0.0059
	(0.0070)	(0.0167)	(0.0074)
I [Precipitation] ≤ 10th percentile	0.0107	-0.0056	0.0113
	(0.0074)	(0.0184)	(0.0075)
L.I [Precipitation] ≥ 90th percentile	-0.0064	0.0134	-0.0077
	(0.0074)	(0.0186)	(0.0075)
L.I [Precipitation] ≤ 10th percentile	0.0037	-0.0143	0.0049
	(0.0084)	(0.0155)	(0.0088)
Observations	5,586	3,779	5,586
Municipalities	51	51	51

* p < 0.1, ** p < 0.05, *** p < 0.01. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A5: The effect of rainfall shocks on formal employment in rice-oriented municipalities

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0407	-0.0833	-0.0497
	(0.0317)	(0.0835)	(0.0306)
I [Precipitation] $\leq$ 10th percentile	0.0952***	0.2769***	0.0829***
	(0.0269)	(0.0873)	(0.0290)
L.I [Precipitation] $\geq$ 90th percentile	-0.0601*	-0.1961***	-0.0502
	(0.0317)	(0.0688)	(0.0314)
L.I [Precipitation] $\leq$ 10th percentile	0.0809***	0.1417**	0.0850***
	(0.0221)	(0.0613)	(0.0244)
Observations	3,392	3,392	3,392
Municipalities	29	29	29

* p < 0.1, ** p < 0.05, *** p < 0.01. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A6: The effect of rainfall shocks on formal earnings in rice-oriented municipalities

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0217**	0.0051	-0.0311***
	(0.0087)	(0.0169)	(0.0097)
I [Precipitation] $\leq$ 10th percentile	0.0295***	0.0196	0.0279***
	(0.0099)	(0.0169)	(0.0088)
L.I [Precipitation] $\geq$ 90th percentile	-0.0096	-0.0019	-0.0135
	(0.0098)	(0.0172)	(0.0101)
L.I [Precipitation] $\leq$ 10th percentile	0.0109	0.0023	0.0090
	(0.0105)	(0.0166)	(0.0110)
Observations	3,392	3,094	3,392
Municipalities	29	29	29

* p < 0.1, ** p < 0.05, *** p < 0.01. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A7: The effect of rainfall shocks on formal employment in maize-oriented municipalities

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.1352***	-0.1427**	-0.1393***
	(0.0291)	(0.0655)	(0.0298)
I [Precipitation] $\leq$ 10th percentile	0.0351*	0.0052	0.0423**
	(0.0179)	(0.0480)	(0.0192)
L.I [Precipitation] $\geq$ 90th percentile	-0.0886***	-0.1471**	-0.0907***
	(0.0249)	(0.0649)	(0.0248)
L.I [Precipitation] $\leq$ 10th percentile	-0.0075	0.0018	-0.0055
	(0.0227)	(0.0485)	(0.0243)
Observations	6,818	6,818	6,818
Municipalities	60	60	60

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A8: The effect of rainfall shocks on formal earnings in maize-oriented municipalities

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0424***	-0.0154	-0.0441***
	(0.0138)	(0.0147)	(0.0136)
I [Precipitation] $\leq$ 10th percentile	0.0096	-0.0064	0.0097
	(0.0091)	(0.0211)	(0.0087)
L.I [Precipitation] $\geq$ 90th percentile	-0.0323***	-0.0237*	-0.0335***
	(0.0121)	(0.0122)	(0.0124)
L.I [Precipitation] $\leq$ 10th percentile	0.0128	-0.0032	0.0109
	(0.0097)	(0.0211)	(0.0093)
Observations	6,818	4,344	6,818
Municipalities	60	60	60

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A9: The effect of rainfall shocks on formal employment in yucca-oriented municipalities

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0557	-0.1433*	-0.0543
	(0.0340)	(0.0801)	(0.0325)
I [Precipitation] $\leq$ 10th percentile	0.0293	0.1503*	0.0326
	(0.0345)	(0.0795)	(0.0353)
L.I [Precipitation] $\geq$ 90th percentile	0.0396	-0.2010**	0.0510
	(0.0406)	(0.0948)	(0.0445)
L.I [Precipitation] $\leq$ 10th percentile	0.0169	0.0241	0.0273
	(0.0304)	(0.0776)	(0.0280)
Observations	3,396	3,396	3,396
Municipalities	29	29	29

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A10: The effect of rainfall shocks on formal earnings in yucca-oriented municipalities

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0417*	0.0140	-0.0479**
	(0.0219)	(0.0141)	(0.0225)
I [Precipitation] $\leq$ 10th percentile	0.0037	0.0018	0.0036
	(0.0187)	(0.0149)	(0.0194)
L.I [Precipitation] $\geq$ 90th percentile	-0.0039	-0.0105	-0.0133
	(0.0201)	(0.0195)	(0.0214)
L.I [Precipitation] $\leq$ 10th percentile	0.0244	-0.0029	0.0253
	(0.0151)	(0.0186)	(0.0161)
Observations	3,396	2,699	3,396
Municipalities	29	29	29

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

A.2 The incidence of Irrigation Systems

Table A11: The effect of rainfall shocks on formal employment in municipalities with low incidence of irrigation systems

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0961***	-0.1151***	-0.0931***
	(0.0143)	(0.0308)	(0.0143)
I [Precipitation] $\leq$ 10th percentile	0.0321***	0.0675**	0.0283**
	(0.0119)	(0.0273)	(0.0119)
L.I [Precipitation] $\geq$ 90th percentile	-0.0709***	-0.1569***	-0.0639***
	(0.0138)	(0.0301)	(0.0139)
L.I [Precipitation] $\leq$ 10th percentile	0.0377***	0.0752***	0.0325***
	(0.0121)	(0.0285)	(0.0120)
Observations	27,677	27,677	27,677
Municipalities	246	246	246

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A12: The effect of rainfall shocks on formal earnings in municipalities with low incidence of irrigation systems

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0256***	-0.0120*	-0.0279***
	(0.0052)	(0.0066)	(0.0052)
I [Precipitation] $\leq$ 10th percentile	0.0106**	-0.0027	0.0116***
	(0.0042)	(0.0071)	(0.0043)
L.I [Precipitation] $\geq$ 90th percentile	-0.0136***	-0.0170**	-0.0158***
	(0.0051)	(0.0069)	(0.0052)
L.I [Precipitation] $\leq$ 10th percentile	0.0170***	-0.0097	0.0189***
	(0.0046)	(0.0073)	(0.0046)
Observations	27,677	19,002	27,677
Municipalities	246	243	246

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A13: The effect of rainfall shocks on formal employment in municipalities with high incidence of irrigation systems

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0949***	-0.1515***	-0.0917***
	(0.0125)	(0.0289)	(0.0122)
I [Precipitation] $\leq$ 10th percentile	0.0319***	0.0603**	0.0322***
	(0.0109)	(0.0233)	(0.0111)
L.I [Precipitation] $\geq$ 90th percentile	-0.0391***	-0.1424***	-0.0346***
	(0.0122)	(0.0288)	(0.0120)
L.I [Precipitation] $\leq$ 10th percentile	0.0189*	0.0556**	0.0172
	(0.0101)	(0.0224)	(0.0104)
Observations	30,618	30,618	30,618
Municipalities	269	269	269

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A14: The effect of rainfall shocks on formal earnings in municipalities with high incidence of irrigation systems

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0303***	-0.0062	-0.0331***
	(0.0052)	(0.0065)	(0.0053)
I [Precipitation] $\leq$ 10th percentile	0.0095**	0.0040	0.0093**
	(0.0038)	(0.0064)	(0.0038)
L.I [Precipitation] $\geq$ 90th percentile	-0.0097**	-0.0052	-0.0118**
	(0.0049)	(0.0066)	(0.0051)
L.I [Precipitation] $\leq$ 10th percentile	0.0096**	0.0024	0.0105**
	(0.0042)	(0.0055)	(0.0043)
Observations	30,618	23,477	30,618
Municipalities	269	268	269

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

A.3 The effects of rainfall shocks on formal rural labor markets, November/2012 to June/2018

Table A15: The effect of rainfall shocks on formal rural employment

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0512***	0.0179	-0.0536***
	(0.0123)	(0.0217)	(0.0127)
I [Precipitation] $\leq$ 10th percentile	0.0000	0.0331*	-0.0011
	(0.0072)	(0.0176)	(0.0076)
L.I [Precipitation] $\geq$ 90th percentile	0.0235**	0.0411*	0.0232**
	(0.0110)	(0.0222)	(0.0114)
L.I [Precipitation] $\leq$ 10th percentile	-0.0203***	0.0202	-0.0229***
	(0.0076)	(0.0163)	(0.0080)
Observations	32,607	32,607	32,607
Municipalities	503	503	503

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.

Table A16: The effect of rainfall shocks on formal rural earnings

	Total	Agricultural	Nonagricultural
	(1)	(2)	(3)
I [Precipitation] $\geq$ 90th percentile	-0.0203***	0.0026	-0.0210***
	(0.0040)	(0.0045)	(0.0040)
I [Precipitation] $\leq$ 10th percentile	0.0014	-0.0030	0.0019
	(0.0028)	(0.0050)	(0.0029)
L.I [Precipitation] $\geq$ 90th percentile	0.0157***	0.0052	0.0152***
	(0.0037)	(0.0048)	(0.0038)
L.I [Precipitation] $\leq$ 10th percentile	-0.0025	-0.0047	-0.0015
	(0.0030)	(0.0044)	(0.0031)
Observations	32,607	26,655	32,607
Municipalities	503	498	503

* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All regressions estimates include municipal–level and month–level fixed effects. Source: Institute of Hydrology, Meteorology and Environmental Studies and Ministry of Health and Social Protection.