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Weather Index Insurance and Shock Coping

Evidence from Mexico's CADENA Program

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Abstract

Weather risk and incomplete insurance markets are significant contributors to poverty for rural households in developing countries. Weather index insurance has emerged as a possible tool for overcoming these challenges. This paper provides evidence on the impact of weather index insurance from a pioneering, large-scale insurance program in Mexico. The focus of this analysis is on the ex-post effects of insurance payments. A regression discontinuity design provides find evidence that payments from weather index insurance allow farmers to cultivate a larger land area in the season following a weather shock. Households in municipalities receiving payment also appear to have larger per capita expenditures and income in the subsequent year, although there is suggestive evidence that some of this increase is offset by a decrease in remittances. While the cost of insurance appears to be high relative to the payouts, the benefits exceed the costs for a substantial range of outcomes.

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Weather index insurance and shock coping: Evidence from Mexico's CADENA program

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1 Introduction

Weather is an important determinant of income for rural populations in developing countries. The short-term impacts of weather shocks can compound into long-term reductions in investments and growth. In the absence of formal insurance markets, smallholder farmers often resort to self-insuring through their choices of low-risk and low-profit investments (Barnett et al., 2008; Rosenzweig and Binswanger, 1993). They also turn to coping strategies, such as selling assets, that reduce their ability to produce income in the future (Rosenzweig and Wolpin, 1993). All in all, the shock coping and risk management mechanisms used by the poor to protect themselves against uninsured risks are at best insufficient and at worst contribute to poverty.

Index-based weather insurance has emerged as a tool that has the potential to provide small-scale farmers with coverage against covariate weather shocks. Most of the evidence regarding the impact of weather index insurance focuses on the determinants of demand or its effect on ex-ante investment decisions, such as planting stage inputs or crop choices (Karlan et al., 2014; Cole et al., 2013; Mobarak and Rosenzweig, 2013). One notable exception is Carter and Janzen (2013), who find that the provision of index insurance reduces costly coping strategies, such as reducing consumption and selling livestock assets, in the event of a shock. Thus, this paper contributes to the relatively limited literature on the ex-post effect of weather index insurance.[1]

We study the impact of weather index insurance in the context of a large-scale government-funded insurance program pioneered by the Mexican government. The program, which goes by the name CADENA, insures smallholder farmers and has achieved widespread coverage by having state and federal governments, rather than individual farmers, pay insurance premiums. By 2013, CADENA insured more than 6 million hectares of cropland (FAO, 2014). The expansive coverage and relatively long tenure of the CADENA program make it a unique setting for evaluating the effects of index insurance. To evaluate the effect of insurance payments, we exploit thresholds built into the insurance in a regression discontinuity design. This design allows us to compare municipalities that received similar weather shocks such that differences in observed ex-post outcomes are

[1] We attempted to study the effects of the insurance on ex-ante risk management strategies. This effect was looked at in a working paper by Fuchs and Wolff (2010), as well as Arias et al. (2014). We were unable to extend the analysis using more recent data because when including additional years, the identifying assumption for the rollout did not hold. We were also unable to exploit the eligibility threshold due to the limited availability of individual-level agricultural data, as well as the small number of farmers who have landholdings close to the eligibility threshold of 20 hectares.

attributable to insurance payments alone.

While data issues affect the robustness of our estimates, this analysis provides some evidence that insurance payments allow farmers to cultivate larger land areas in subsequent growing seasons, consistent with the presence of credit constraints that result in diminished investment following a weather shock and/or learning about the reliability of insurance payments. The insurance payments also result in higher household expenditures per capita, indicating welfare gains, although some of the benefits may be offset by a reduction in transfers from abroad.

The remainder of the paper is organized as follows, section 2 provides background about the CADENA program and outlines the data used in the evaluation. Section 3 describes the empirical strategy, while section 4 provides the results. Section 5 discusses the costs and benefits of the insurance provided through CADENA, and section 6 concludes.

2 Background and Data

With a rural population of approximately 27 million and two-thirds of the country's poor living in rural localities (INEGI), weather risk is an important issue for poverty reduction efforts in Mexico. To address this issue, the federal government began a weather index insurance program in 2003, which was administered through the Ministry of Agriculture (SAGARPA). The purpose of this program was to provide relief to smallholder farmers when crop failures occurred but to do so in a way that made government expenditures more predictable. The federal government has promoted the use of insurance by subsidizing up to 90% of premium payments paid by state governments,[2] while gradually reducing the percentage of funds it contributes to ex post relief via the Direct Support scheme (*Apoyos Directos*). While individual farmers are not insured directly, state governments receive indemnity payments and distribute them to affected farmers.[3]

This program, called CADENA, began with drought index insurance covering small maize and sorghum farmers in one state in Mexico. The program has expanded significantly since its inception in both geographic scope and breadth of coverage. CADENA now offers weather index insurance for a variety of perils (e.g., drought, flood, hail), as well as area-based yield index insurance, which

[2] Subsidies from the federal government depend on the marginality index of the insured municipality, as computed by CONAPO.

[3] These funds can also be used to fund infrastructure projects in affected communities.

provides payment when the average yield in an area, as determined by a random sample, falls below a threshold. Moreover, CADENA also offers traditional and remote sensing index insurance for livestock (Arias et al. 2014). This analysis will focus on the drought index insurance because it has historically been the largest component of the CADENA program, and going forward we will simply refer to it as index insurance. Through this index insurance component, CADENA currently insures farmers growing staple crops on less than 20 hectares of rainfed land (SAGARPA, 2014). The insurance provides coverage during three pre-determined phases that run from sowing to harvesting. If precipitation as measured by the corresponding weather station falls below the threshold in any of the three phases, the insurer makes indemnity payments to the state, which in turn transfers these to eligible farmers in the insured area. Because of restrictions regarding the maximum distance between the weather station and the insured area, a municipality may be insured by multiple policies each linked to a different station.

The data for this evaluation come primarily from four sources. Policy data from SAGARPA include information on the insured crop, rainfall triggers and corresponding stations, area insured, and record of all payouts for each insured municipality for the period 2005 to 2013. Weather data from the National Water Commission (CONAGUA) allow us to calculate the precipitation at each of the weather stations linked to an insurance policy, which in turn is compared to the policy thresholds and used to determine if that policy should have paid out. To determine the effect of insurance payments on yields and area sowed, we use agricultural production data from SAGARPA detailing the annual hectares sowed, hectares harvested, and total production in metric tons at the municipality-crop level. Lastly, to study the economic impacts of the insurance, we use national household income and expenditure surveys (ENIGH), which are carried out every other year with the latest one occurring in 2014. These household expenditure and income surveys are repeat cross-sections of households with a rotating sample of municipalities.[4] Households are surveyed between the months of August and November and the income, expenditure, and remittance variables refer to the previous three months. Lastly, the analysis sample when using ENIGH data is limited to households living in rural localities. The Mexican Statistical Institute (INEGI) defines rural localities as those with less than 2,500 inhabitants.

[4]The rotating sample means that in any given year some insured municipalities will not be included in the analysis sample because they do not have income or expenditure data, which substantially decreases the sample of municipalities for analyzing economic outcomes.

3 Empirical Strategy

This evaluation of the CADENA program focuses on the effect of insurance payments on ex-post production decisions and other coping mechanisms. To identify this effect, we limit our sample to municipalities that were insured through drought index insurance policies between the years of 2005 and 2013. Using weather data provided by CONAGUA, we match policies to their corresponding weather stations and calculate the total precipitation recorded at that station within each of the three phases designated in the policy. We then subtract the policy-specific precipitation threshold from the realized precipitation to obtain deviations from the threshold for each of the three phases, $X_{mcsti} = precip_{mcsti} - threshold_{mcsti}$, where m indexes the municipality, c the crop, s the weather station, t the year, and i the phase. A policy results in payment if precipitation at the corresponding weather station falls below the pre-determined threshold in any of the three phases.

In an ideal setting, we would observe insurance payments and all relevant outcomes for precisely the area covered by the policy. The running variable in this setting would be the minimum deviation from the threshold at a given weather station over the three phases of the policy: $X_{mcst} = \min_{i\in\{1,2,3\}}\{X_{mcsti}\}$. However, we only observe payment and outcome variables at the municipality level, so we collapse the observations to the municipality-crop-year level and define the running variable as the minimum deviation from the threshold over all of the weather stations associated with a given municipality, $X_{mct} = \min_{s\in S(m)}\{X_{mcst}\}$. Given the data limitations, we have to account for the fact that there is substantial heterogeneity in the intensity of the treatment among municipalities receiving payment because some municipalities may have received payouts on 25% of their insured area and others may have received payment on 100%. In addition, there exists variation in terms of the percentage of agricultural land in the municipality that is insured via CADENA, since the policy is limited to land cultivated by producers with less than 20 hectares of land. Thus, the treatment variable is defined as the total number of hectares (across all weather stations linked to a given municipality) that received a payout divided by the number of hectares of land devoted to that crop in a given municipality:

$$T_{mct} = \frac{hapaid_{mct}}{\overline{ha_{mc}}}$$

Missing weather data combined with the way in which treatment variable is defined results in a fuzzy RD, so the treatment effect is estimated via two-stage least squares. Specifically, we estimate the following equations:

$$T_{mct} = \alpha_0 + \beta_0 Z_{mct} + \gamma_0 X_{mct} + \pi_0 X_{mct} \cdot Z_{mct} + \delta_0^c + \varepsilon_{mct} \tag{1}$$

$$y_{mct+1} = \alpha_1 + \beta_1 Z_{mct} + \gamma_1 X_{mct} + \pi_1 X_{mct} \cdot Z_{mct} + \delta_1^c + \tilde{\varepsilon}_{mct} \tag{2}$$

Equation 1 estimates the first stage by regressing treatment, T_{mct}, on $Z_{mct} = \mathbf{1}\{X_{mct} < 0\}$, an indicator for falling below the threshold amount of rainfall. Equation 2 is the reduced form, which estimates the effect of falling below the threshold on the outcome of interest in the following year, y_{mct+1}. Thus, the coefficient of interest is $\beta_{2SLS} = \dfrac{\beta_1}{\beta_0}$. For regressions where we have observations at the crop level, we include crop fixed effects. The analysis is restricted to insurable crops (i.e., maize, beans, sorghum and barley) unless we explicitly note otherwise. Household level regressions using ENIGH data are estimated with a similar set of regressions, where observations are no longer indexed by crop c, but are now indexed by h to indicate an individual household. In keeping with the regression discontinuity design, these regressions are restricted to a sample of data within a narrow bandwidth of the normalized threshold of zero.

4 Results

4.1 Main results

We begin by looking at some descriptive statistics for the analysis sample in table 1. The analysis sample for the agricultural outcomes is composed of 976 unique municipalities over 8 years with 4,311 total observations. As mentioned before, the way in which the ENIGH sample is constructed results in a smaller number of unique municipalities for our economic regressions (192)[5] but multiple observations per municipality for a total sample size of 5,879. In panel A, we

[5]Given the large number of municipalities that get dropped from the ENIGH panel, we present summary statistics for the two different samples in Appendix Table 9. While the municipalities in the ENIGH sample have much larger populations, they are very similar along other dimensions with only the education variables showing even marginally significant differences.

see that the mean of the running variable (deviation from the precipitation threshold) is 71 mm, suggesting that in an average year a municipality can expect to receive rainfall in excess of the threshold. This result is reinforced by the fact that only 11% of the observations in our sample have rainfall realizations that fall below the insurance threshold. Another statistic worth noting is that the average change in hectares sowed from one year to the next is close to zero, such that there is no evidence of a monotonically increasing or decreasing trend in the area sowed. Turning to panels B and C, we see evidence that points to a strong first stage, which will be formally tested in a subsequent section. Specifically, the mean of the running variable is positive for municipalities that do not receive payment in a given year, and only four percent of these observations receive rainfall below the threshold. We contrast these results with observation that receive payment in that year, and we see that the mean of the running variable is negative (i.e., precipitation falls below the threshold) and 77% of these observations have rainfall realizations that should trigger insurance, as would be expected if these rainfall thresholds are generally enforced.

To understand the need for index insurance, we explore in more detail the relationship between rainfall and yields prior to the introduction of CADENA. In figure 1, we plot a local regression of log yield on total precipitation in the growing season.[6] The points on the graph represent the average yield in 50 mm bins, taking observations over all crops and municipalities in our sample period.[7] As can be seen, there is a positive relationship between precipitation and yields until about 1,000 mm of precipitation. To put this result in context, the average insurance threshold is about 230 mm of precipitation over the entire growing season, and the average yield at this level of precipitation is about 23% of the maximum yield.[8] Table 2 reports the results of a regression of log yield on precipitation, the coefficient on mm of precipitation is 0.0105, while the coefficient on mm of precipitation^2 is -0.000237, mirroring the inverse-U relationship we see in figure 1. We take this as evidence that farmers who depend on rainfed agriculture suffer losses when precipitation falls below the thresholds established in the insurance policies. This fact is necessary to contextualize the effects we observe in subsequent analyses.

To ensure the validity of the research design, we must first ensure that the treatment variable,

[6] We define the growing season as the period covered by the insurance policy once CADENA comes into effect.

[7] A similar plot using residuals of a regression of log yield on crop fixed effects looks very similar.

[8] The thresholds are defined separately for three different parts of the growing season. For illustrative purposes, we sum the three thresholds for each municipality and average over all municipalities to obtain 230 mm.

in this case the percentage of hectares receiving payment, changes discontinuously at the threshold. Figure 2a, gives a graphical representation of this first stage, in which we see that there is a discrete change in the treatment variable of about 20% at the threshold. Given that the average municipality that receives payment has a value of the treatment variable of about 45%, this is similar to a 50% increase in the probability of receiving any payment at all.

One of the stated aims of the CADENA program is to ensure that farmers who have suffered negative weather shocks have sufficient resources to purchase inputs for the next growing season. We cannot observe input purchase, but if the insurance is serving its intended purposes, these input purchases should be translating into improved agricultural outcomes in either the area sowed or the yields. Thus, we begin this analysis by estimating the effect of insurance payment on the change in log hectares sowed from t to $t+1$ and the yield in $t+1$. Table 3 shows the results of estimating equations 1 and 2 with yield and Δ log hectares sowed of insured crops as the outcomes. Column 1 reports the results for Δ log hectares sowed using the optimal bandwidth, which was calculated following the procedure in Calonico et al. (2014).[9] Using this optimal bandwidth, we find a reduced form effect of approximately 8% reported in panel B, which is also depicted in figure 2b. Panel C reports the two-stage least squares estimate of 0.39, which is statistically significant at the 5% level. This estimate implies that for a a particular crop, increasing the percentage of hectares that received payment from 0 to 100% would increase the amount of land devoted to that crop by 39% relative to the previous year. Given that the average treatment municipality receives payment for 45% of said land, we would expect the average effect of receiving payment to be approximately 17%. In columns 2 and 3, we show alternative specifications for robustness. Column 2 shows results for a larger bandwidth of 70 mm, and column 3 shows results using the entire sample but controlling for a quadratic, rather than linear, function in the running variable. While the results are no longer significant at conventional levels, the estimates are very stable across the three specifications. For the yield regressions, none of the results are statistically significant and the point estimates are less stable.

In table 4, we also analyze the impact of insurance payment on total area sowed, including non-insured crops. Using the optimal bandwidth, reported in column 1, we find a point estimate

[9] The optimal bandwidth varied slightly for different outcomes, so we used 50 mm across all outcomes to maintain consistency.

of 0.288. This point estimate is about 73% as large as the estimate when considering only insured crops. Given that in the average municipality 76% of the land is devoted to insured crops, this result suggests that the increase in total land area is coming almost exclusively from insured crops. The results using alternative specifications, reported in columns 2 and 3, are similar in magnitude, although less precisely estimated. Two potential mechanisms can explain these results: learning about insurance policies and credit constraints. In the first mechanism, farmers either do not trust that payments will be made in case of a weather shock or there is some ambiguity about how the policies work. When they receive a payment following a weather shock the ambiguity and/or uncertainty is resolved, and given the promise of insurance coverage they now find it optimal to expand the area under cultivation with insured crops. This mechanism is consistent with the result that the area expansion comes mostly from insured crops. The second alternative is that after a bad harvest farmers do not receive sufficient income to cover the cost of inputs for the following growing season, and the presence of credit constraints means they cannot borrow funds to optimally invest in inputs. The inflow of cash from insurance payments eases this credit constraint. While farmers with such a constraint would face a tradeoff between yield on a given plot and total area sowed, their decision to put inputs toward sowing a larger land area is reasonable given that any additional area they sowed would be insured, but they would not receive a larger payment for plots with higher expected yields. In interviews carried out in Mexico, farmers have said that the payments of 1,500 pesos/ha provided by the insurance do not fully cover the cost of inputs for the average plot of that size. Lastly, these two mechanisms are by no means mutually exclusive such that the observed impacts reflect a combination of the two effects.

Next, we turn to economic outcomes as measured in the household income and expenditure surveys. Panel C of table 5 reports the 2SLS estimates of the effect of insurance payment on log expenditures per capita and log income per capita. In column 1, we see the point estimate for log expenditures per capita using the optimal bandwidth. The point estimate is large at 0.613, although it is somewhat noisy and only significant at the the 10% level. Column 3 reports a point estimate for log income per capita of 0.852, which is significant at the 5% level. Thus, going from a municipality that receives no payment to the average treatment municipality (i.e., 45% treated) we would expect increases in expenditure and income per capita of approximately 27% and 38%, respectively. Comparing these point estimates to alternative specifications suggests that they are relatively robust.

Table 6 reports the results for remittances. The outcome variable in this case is an indicator for whether a municipality received any remittances in the previous three months. Our preferred point estimate, reported in column 1, is -0.345, suggesting that for the average municipality, receiving insurance payment reduces the percentage of households receiving remittances by about 15%. Considering that only 12% of households have received remittances in the previous three months, this estimate suggests that receiving insurance payments essentially reduces remittances to zero. However, it is important to keep in mind that this point estimate is somewhat noisily estimated and is only significant at the 10% level.

To better understand these effects, consider the fact that in a set of focus group interviews, the majority of farmers reported having between 4 and 8 hectares of land. On average, about half of the insured hectares receive payments of 1,500 pesos/ha, such that the average household could expect to receive between 3,000 and 6,000 pesos. Meanwhile, we observe that household incomes and expenditures per capita increase about 30 to 40% as a result of payment. The mean of both total household expenditures and total household income in the sample of rural localities is approximately 20,000 pesos[10], such that an increase of 30 to 40% implies 6,000 to 8,000 pesos in additional income. The timing of the survey is such that this increase in income should come primarily from increases in the value of the harvest or investments made in other income-producing activities using the insurance payments. A minority of the households in the sample may be receiving substantially delayed CADENA payments within this period of time. Thus, if we ignore the effect on remittances for a moment, these results suggest that every peso provided in insurance payment results in 1 to 2.7 additional pesos of income and/or expenditure for farmers, keeping in mind that the coefficients underlying this calculation are rather imprecise. Now, the point estimates suggest that remittances essentially decrease to zero from a mean of 764 pesos.[11] This result implies that the gross increase in other income sources for treated households must be approximately 6,750 to 8,750 pesos, which in turn changes the rate of return modestly to be in the range of 1.1 to 2.9 pesos of additional gross income per peso of insurance payment.

While our estimates are imprecisely measured, resulting in a large range of potential impacts,

[10]This is income received in the past three months.
[11]This figure included the majority of households that receive no remittance income.

we think this analysis provides suggestive evidence that CADENA payments increase household income and expenditures but possibly crowd out remittances. The observed short-term effects of CADENA on income and expenditures bolster the results of an analysis carried out by Arias et al. (2014). The authors find that between 2000 and 2010, moderate income poverty decreased 1.78 percentage points in CADENA insured municipalities relative to those that were ineligible for the program. Meanwhile, the effect on remittances is in line with other research finding that formal transfers may substitute informal risk sharing mechanisms or other transfers. For example, Albarran and Attanasio (2004) show that the cash transfers provided by the PROGRESA program in Mexico crowd out private transfers. Yang and Choi (2007) and Cox, Hansen, and Jimenez (2004) study this phenomenon in the context of the Philippines and find that private transfers are highly sensitive to changes in income. These two studies point to the role of remittances as insurance. As such, it is reasonable to think that when formal insurance payments are made, the need for remittances is diminished. An alternative way of interpreting this result is that remittances make up for the basis risk inherent in index insurance. Mobarak and Rosenzweig (2013) find that the presence of basis risk in weather insurance makes subcaste-based informal risk-sharing a complement to weather index insurance in India. In the presence of basis risk, very risk averse individuals may have no or very low demand for index insurance (Clarke 2016) because the disutility of the worst case scenario where they suffer a shock and receive no payouts outweighs the benefits of the insurance. However, if informal risk sharing networks can make transfers in this worst case scenario, then index insurance and informal insurance are actually complements. It may be the case that migrants abroad send transfers in response to shocks that do not result in insurance payments.

4.2 Falsification tests

The validity of the research design relies on the assumption that potential outcomes are smooth across the insurance threshold. Because potential outcomes are unobservable, we first test this assumption by ensuring that the density of the running variable is continuous across the threshold. If we were to observe bunching around the threshold, that would suggest that a municipality can manipulate the amount of rainfall recorded at the weather station to ensure that it receives a payout. Such a scenario would violate the assumptions on which the research design rests.

Although this scenario is unlikely given that weather stations are run by a separate government entity and the information recorded is used for a variety of civilian and military purposes, we can test this assumption using the McCrary sorting test (McCrary 2006). Figure 4 is a visual representation of this test. The solid line is the estimated density of the running variable using local linear regression. The dashed lines represent confidence intervals for the estimated density. The overlapping confidence intervals imply that there is no discontinuous change in the density across the threshold. Formally, the p-value for the McCrary test is 0.49, so we fail to reject the null hypothesis that the density of the running variable is smooth across the threshold.

Another test of the identifying assumptions can be carried out using pre-CADENA data. Before CADENA is in place, we should not see any effect of crossing the insurance policy threshold on outcomes in the following season because no insurance payments would be made. Figures 5a and 5b, show that there does not seem to be a discrete jump in either Δ log hectares sowed or yield in t+1 across the threshold. Table 7 shows the results of the equivalent regressions. For Δ log hectares sowed, none of the different specifications show significant results and the point estimate using the preferred bandwidth is much smaller than what was obtained when estimating the same equation on the analysis sample. For log yield, the point estimate is not significant using the preferred bandwidth. If the regression is estimated on the entire sample of data, the point estimate is negative and significant at the 10% level, suggesting that there may be some bias in the estimates using this specification. Overall, these tests suggest that our results are not driven primarily by some omitted variable bias.

5 Costs of Insurance

Having analyzed the benefits of the CADENA program, we now turn to the costs. Table 8 shows the total sum insured, premium payments, indemnity payments, and loss ratio (indemnity payments/premium) for all weather index insurance policies from 2005 to 2013. We see that the amount insured and premium payments have steadily increased over time, due both to the geographical expansion of the program and an increase in the amount insured per hectare. Indemnity payments, however, fluctuate from year to year, as is expected given that they depend on stochastic weather outcomes. Correspondingly, the loss ratio in a given year, also fluctuates from 104% in 2005 to 25% in 2012. However, these results mask a lot of heterogeneity across states. If we look at the average loss ratio by state over the period 2005-2013 in figure 6, we see that it varies from zero, primarily for states participating only a few years, to more than 100% for the states of Tabasco, Tamaulipas, Nayarit, and Quintana Roo. Likewise, if we focus on the years with the largest loss ratios (2005, 2009, and 2011), we see in figure 7 that even in these years a substantial number of states get no indemnity payments, while others have loss ratios exceeding 200%. These results suggest that there is a significant amount of heterogeneity in indemnity payments across states in any given year, as well as over the entire period in question.[12] We can also approximate the pure premium and consequently the loading for these policies with the caveat that these calculations are usually undertaken over a longer period of time than the eight years of data available to us. The pure premium is obtained by dividing the total indemnity payments ($\sim$ 1.35 B MXN) by the total amount insured ($\sim$ 12.18 B MXN), resulting in a pure premium of 11%. We can calculate a similar percentage for the actual premiums paid ($\sim$ 2.33 B MXN), which give us 19%. Thus, the actual premiums paid represent a 73% increase over the pure premium. The OECD notes that transactions costs for crop insurance can be as high as 30 to 40% (OECD 2011), making a loading factor of 73% seem high for an index insurance that has been established for almost a decade. Nevertheless, the relatively short period of time covered by our data means these results are merely suggestive.

Lastly, we can contextualize the income effects of the program relative to its costs for a rough cost-benefit analysis. To calculate the benefit that a municipality obtains from insurance payment,

[12] We examined the correlation between loss ratio and variables such as GDP, GDP per capita, and average maize yield, but none of these correlations were significantly different from zero.

we employ the following formula:

$$\Delta Income_m = (\beta_{income} \cdot \bar{y}) \times (\bar{T} \cdot \bar{N}_m)$$

The first part of the formula calculates the benefit at the household level by taking the point estimate for the increase in log income per capita reported in column 4 of table 5 (0.852) and multiplying it by the average per capita income (5,935 MXN).[13] This quantity is, in turn, multiplied by the number of affected individuals per municipality. To calculate the number of affected individuals, we take the number of procampo beneficiaries per municipality (942.96) and multiply this by 45%, since on average 45% of the hectares in a treated municipality receive payment. This gives us a total benefit of 2.15 M MXN per municipality, which is multiplied by the number of payouts we observe (998) to obtain a total benefit of 2.12 B MXN. Given the uncertainty in our estimates, we follow the same procedure using the 5% confidence interval for our β_{income} and obtain a range of 359.40 M to 3.88 B MXN for the estimated benefits. This compares to a program cost of 2.35 B MXN. We conclude that our estimates for the impact of CADENA are too imprecise to definitely determine whether the program is cost-effective. However, for a significant range of estimates, the benefits exceed the costs. Moreover, this exercise accounts only for a portion of the benefits of the CADENA program since we are not able to causally identify the risk management effect.

6 Conclusion

This paper contributes to the literature on index insurance by exploring the effects of insurance payment on ex-post investment decisions and coping mechanisms. This analysis is valuable because it is carried out in the context of a large weather index insurance program with almost national coverage. In contrast to much of the existing evidence on index insurance, we are also able to observe effects several years after the start of coverage. There exist some data issues that negatively impact the precision and robustness of our results. These issues include, lack of payment data at the weather station level, missing data from some weather stations, and limited overlap between the set of insured municipalities and the set of municipalities represented in household expenditure and income surveys in any given year. Nevertheless, we believe that this analysis provides suggestive

[13] As mentioned earlier, this is per capita income for the three months prior to the ENIGH survey.

evidence that index insurance has the possibility of improving welfare for rural households by providing resources to invest in the subsequent planting season, which in turn results in more land sowed. The payments may also prevent households from resorting to costly coping mechanisms, such as reducing consumption, as evidenced by the result for household expenditures. Lastly, there appears to be some interaction between formal insurance payments and remittances that reduces the burden of private transfers for relief assumed by migrants. Additionally, we conclude that future evaluations of CADENA or similar programs would benefit from more detailed agricultural production data and administrative records.

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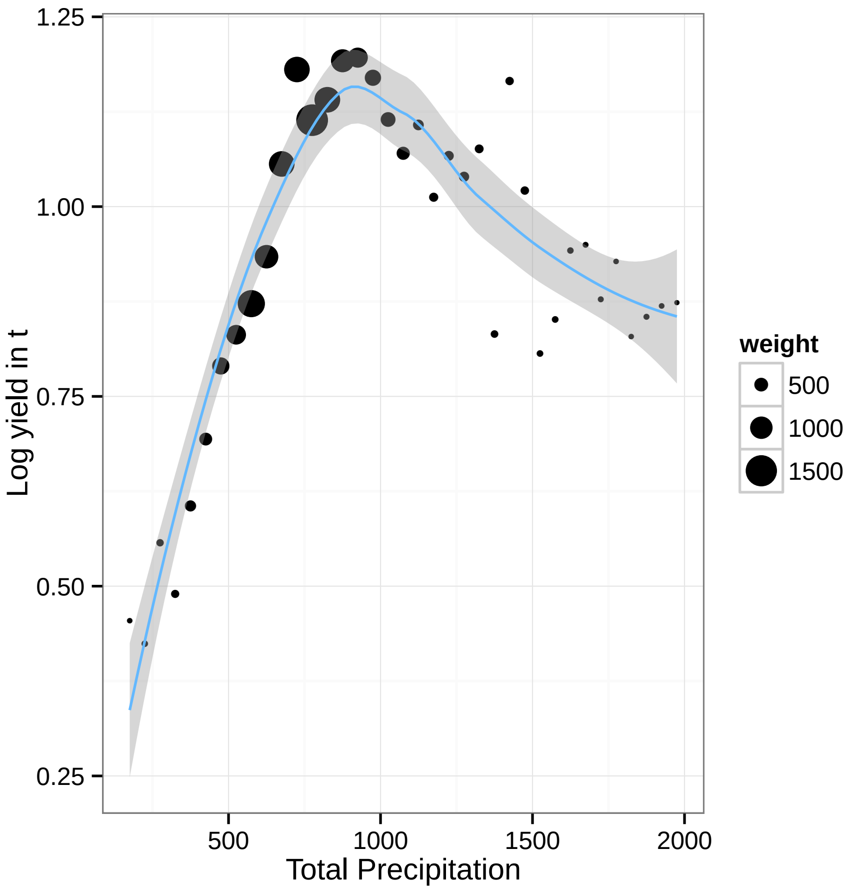
8 Figures

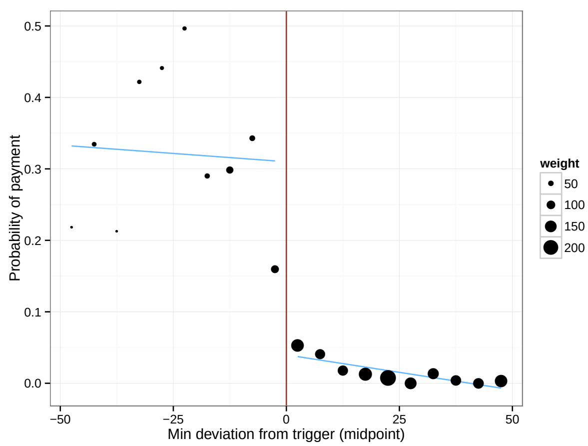
Figure 1: Pre-CADENA: Precipitation and Yield



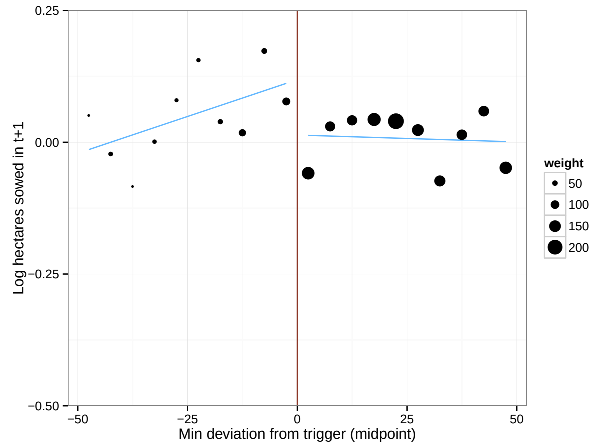
(a) log yield in t as a function of total precipitation

Note. This figure depicts the relationship between log yield and precipitation for insurable crops (maize, beans, barley, sorghum) before CADENA is rolled out in each municipality (e.g., if a municipality is insured for the first time in 2008, we include observations up to 2007). Each circle depicts the average of log yield for all observations (municipality-crop-year) within 50 mm precipitation bins. The size of the circle represents the number of observations. The blue line depicts a loess smoother, while the gray shaded area represents the 5% confidence interval.

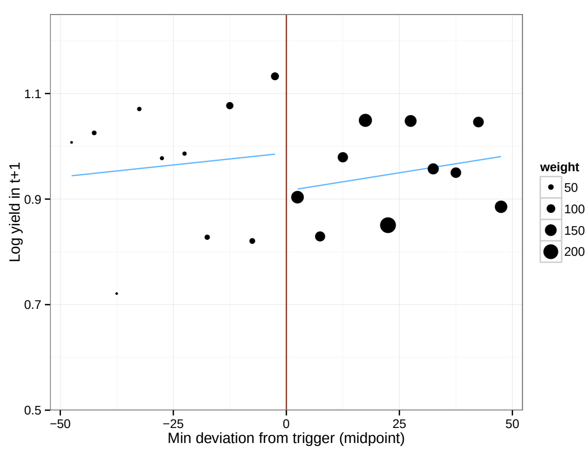
Figure 2: Discontinuity in agricultural outcomes at payment threshold



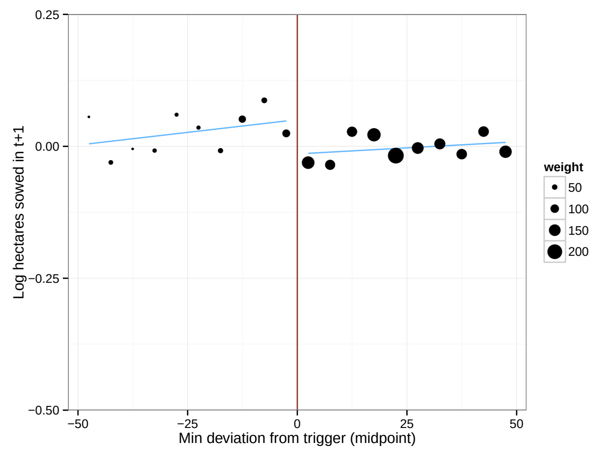
(a) First stage: Probability of payment



(b) Δ log planted in $t+1$ (insured crops)



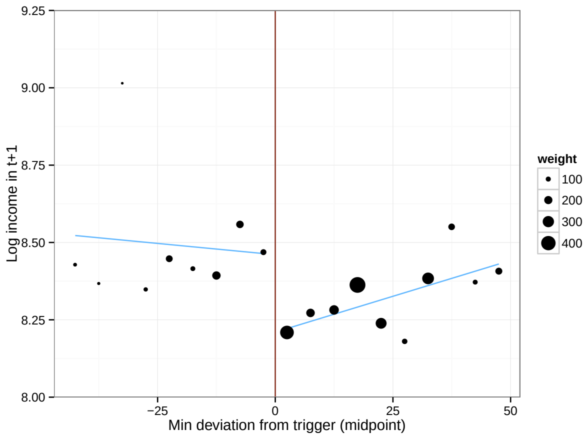
(c) Log yield in $t+1$ (insured crops)



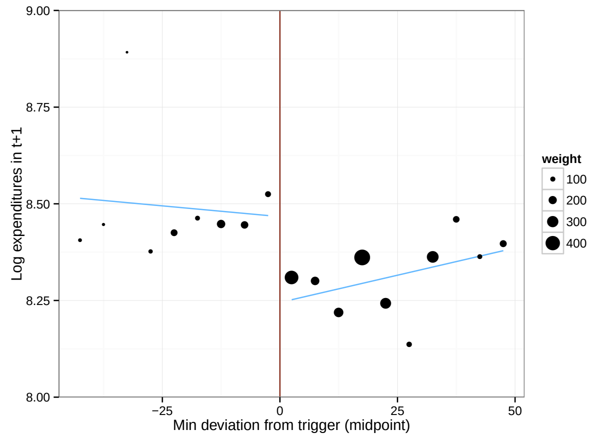
(d) Δ log planted in $t+1$ (All crops)

Note. The figures plot the local average of the respective outcome variable in 5 mm bins. The size of the circle indicates the number of observations in each bin. The blue lines represent linear regressions on the binned averages estimated separately on each side of the normalized threshold. The running variable is calculated by taking the minimum difference between realized rainfall and the threshold at the municipality level. The sample in these figures is limited to observations within the optimal bandwidth of 50 mm.

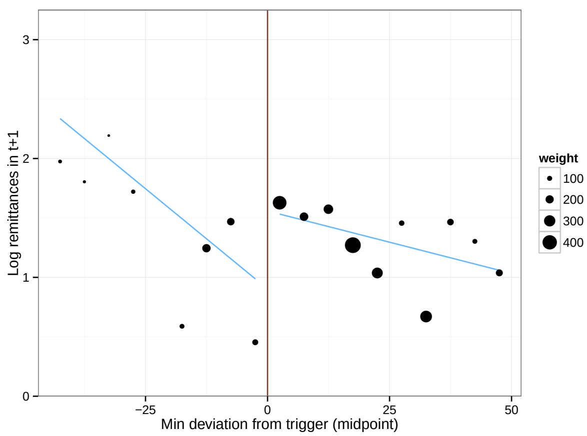
Figure 3: Discontinuity in economic outcomes at payment threshold



(a) Log total income per capita in $t + 1$



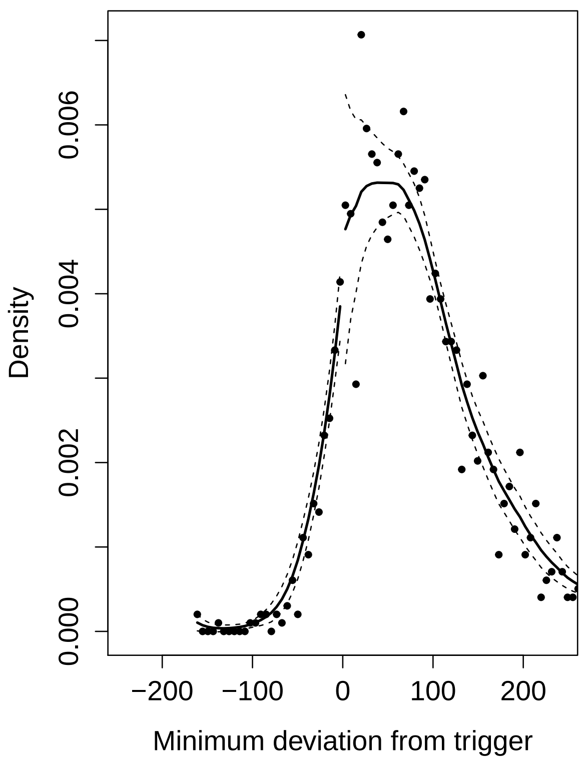
(b) Log total expenditures per capita in $t + 1$



(c) Log remittances in $t + 1$

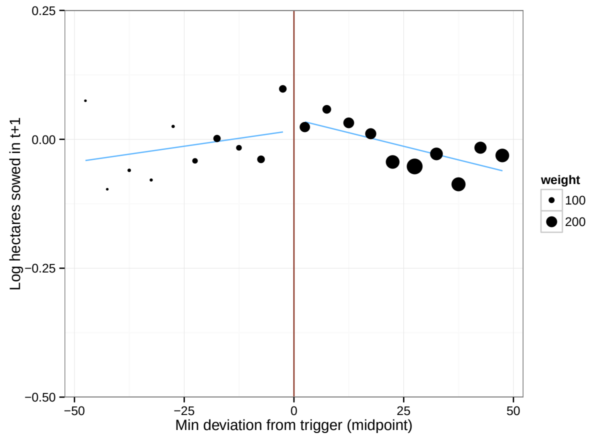
Note. The figures plot the local average of the respective outcome variable in 5 mm bins. The size of the circle indicates the number of observations in each bin. The blue lines represent linear regressions on the binned averages estimated separately on each side of the normalized threshold. The running variable is calculated by taking the minimum difference between realized rainfall and the threshold at the municipality level. The sample in these figures is limited to observations within the optimal bandwidth of 50 mm.

Figure 4: Density of running variable across threshold

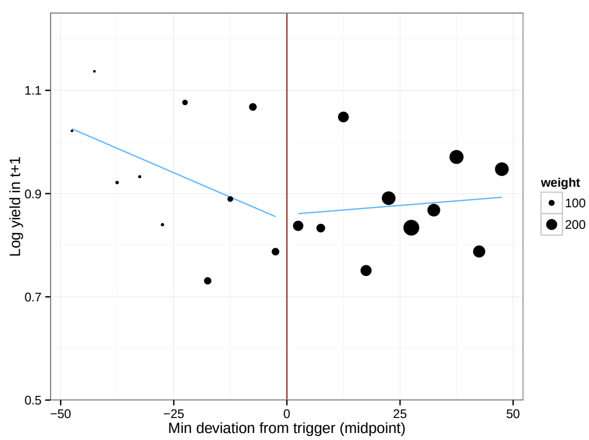


Note. This figure is a visual representation of the McCrary sorting test. The points represent the density of the distribution for different bins of the running variable. The black line represents a local linear smoother, estimated separately to the left and right of the threshold, while the dashed lines represent the 5% confidence interval.

Figure 5: Placebo: Discontinuity in agricultural outcomes at payment threshold



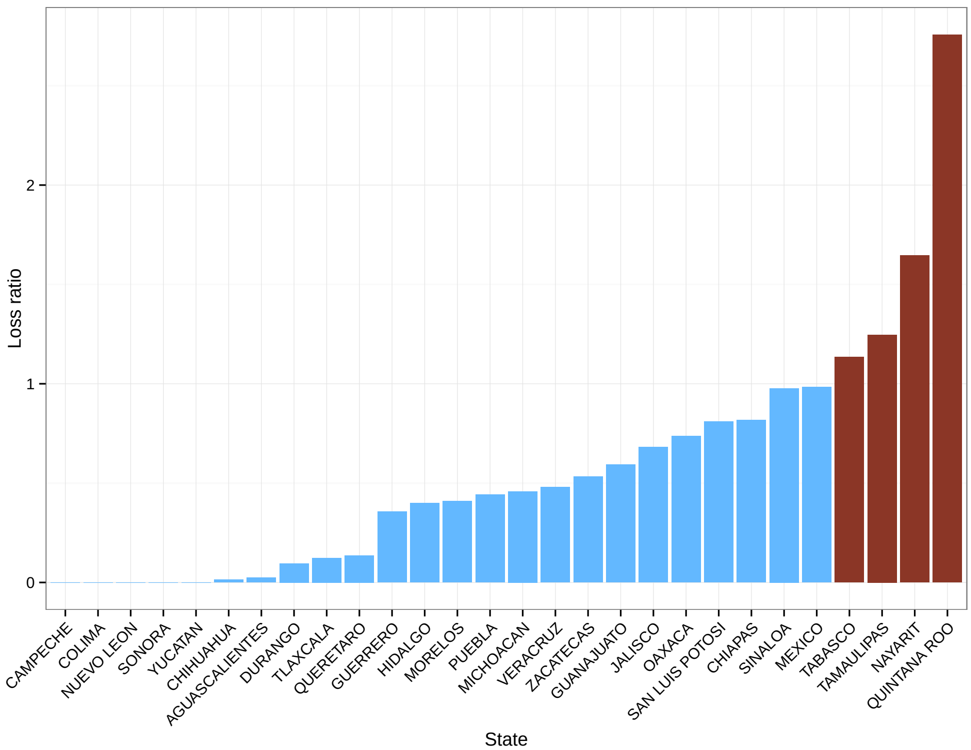
(a) Δ log planted in $t+1$ (insurable crops) - Pre-CADENA



(b) Log yield in $t+1$ (insurable crops) - Pre-CADENA

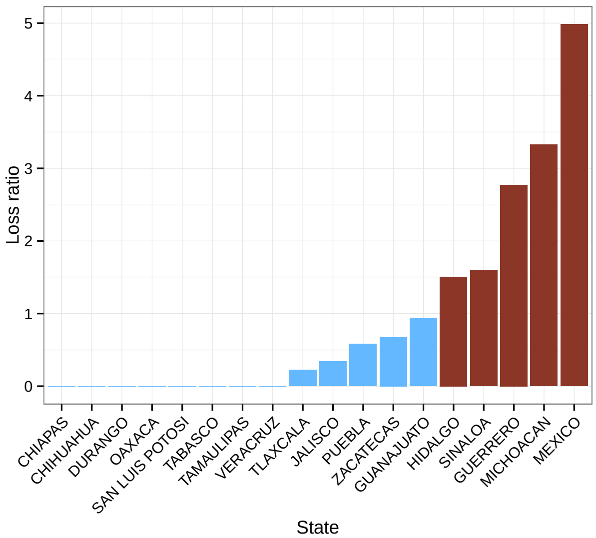
Note. The figures depict placebo tests using our main specification with pre-CADENA data. We plot the local average of the respective outcome variable in 5 mm bins. The size of the circle indicates the number of observations in each bin. The blue lines represent linear regressions on the binned averages estimated separately on each side of the normalized threshold. The running variable is calculated by taking the minimum difference between realized rainfall and the threshold at the municipality level. The sample in these figures is limited to observations within the optimal bandwidth of 50 mm.

Figure 6: Loss ratio by state (2005-2013)

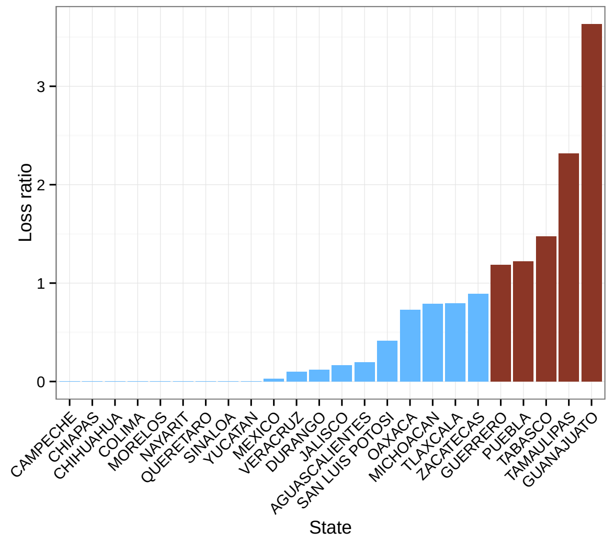


Note. This figure shows the loss ratio (indemnity payments/premium payments) by state over the entire sample period (2005-2013). States with a loss ratio exceeding 100% are highlighted in burgundy.

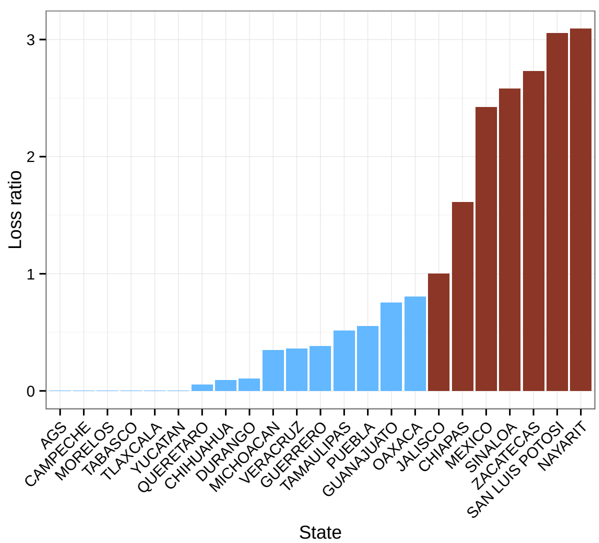
Figure 7: Loss ratio by state for selected years



(a) Loss ratio by state in 2005



(b) Loss ratio by state in 2009



(c) Loss ratio by state in 2011

Note. The figures show the loss ratio (indemnity payments/premium payments) by state for selected years. States with a loss ratio exceeding 100% are highlighted in burgundy.

9 Tables

Table 1: Summary statistics

Variable	Observations	Municipalities	Mean	Std. Dev.
Panel A: All				
Minimum deviation	4311	976	71.07	83.09
Min deviation < 0	4311	976	0.11	.32
% ha receiving payment	4311	976	0.04	0.16
Δ log ha sowed	4311	976	-.01	.47
Log ha sowed	4311	976	7.50	1.36
Log yield	4311	976	0.99	0.55
Log income p.c.	5879	192	8.35	0.79
Log expenditure p.c.	5879	192	8.36	0.76
Remittances	5879	192	764.36	3050.78
Remittances > 0	5879	192	0.12	0.33
Panel B: Payment = 0				
Minimum deviation	3900	943	80.24	81.28
Min deviation < 0	3900	943	0.04	0.20
% ha receiving payment	3900	943	0	0
Panel C: Payment = 1				
Minimum deviation	411	267	-15.85	37.23
Min deviation < 0	411	267	.77	0.42
% ha receiving payment	411	267	0.45	0.32

Note. Rainfall and agricultural variables in panel A come from the agricultural panel, which has municipal-level observations and consists of policy data merged with agricultural production data, as do the statistics in panels B and C. The economic variables in panel A come from the economic panel, which consists of household level observations from ENIGH merged with policy data.

Table 2: Pre-CADENA effect of rainfall on yield

	(1)	(2)	(3)	(4)
	log yield	log yield	log yield	log yield
Minimum deviation from trigger (100s)	0.00661*	0.0129**		
	(0.00344)	(0.00540)		
Minimum deviation^2		-0.00144**		
		(0.000645)		
Total precipitation (100s)			0.00308***	0.0105***
			(0.00111)	(0.00271)
Total precipitation^2				-0.000237***
				(0.0000575)
N	17948	17948	17045	17045
Mean (s.d.) of independent var	1.16 (1.19)	1.16 (1.19)	8.92 (4.99)	8.92 (4.99)
Effect of 1 S.D. decrease	-0.8%	-1.7%	-1.5%	-5.8%

Note. Standard errors are clustered at the municipality level. Asterisks indicate statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The sample is restricted to insurable crops (maize, beans, sorghum barley). All regressions include crop fixed effects and are estimated using only pre-CADENA data from each municipality. Column 1 displays the results of regressions log yield on the minimum deviation from the precipitation threshold that is established once CADENA is in place, while column 2 includes a quadratic term in the explanatory variable. Column 4 displays the results of regressions log yield on the total precipitation within the growing season defined by future insurance policies, while column 2 includes a quadratic term in the explanatory variable.

Table 3: Agricultural outcomes (insured crops) at time $t+1$

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: First Stage						
	payment = 1					
Below trigger	0.194***	0.197***	0.201***			
	(0.0578)	(0.0673)	(0.0553)			
Panel B: Reduced form						
	Δ log ha sowed			log yield		
Below trigger	0.0765**	0.0571	0.0604	0.0733	0.107	0.0242
	(0.0357)	(0.0404)	(0.0448)	(0.0596)	(0.0755)	(0.0518)
Panel C: 2SLS						
	Δ log ha sowed			log yield		
% ha $\widehat{\text{receiving}}$ payment	0.394**	0.291	0.301	0.377	0.545	0.120
	(0.194)	(0.201)	(0.218)	(0.340)	(0.466)	(0.260)
Bandwidth	50	70	all	50	70	all
Polynomial	linear	linear	quadratic	linear	linear	quadratic
N	1916	2502	4311	1916	2502	4311

Note. Standard errors are clustered at the state level. Asterisks indicate statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Observations are at the municipality-crop-year-level. Agricultural production is for the corresponding insured crop (maize, beans, sorghum, and barley). All regressions include crop fixed effects. Panel A shows results from the OLS estimation of the first stage, which corresponds to estimating equation 1. Panel B shows results from the OLS estimation of the reduced form, which corresponds to estimating equation 2, and panel C displays 2SLS estimates. Columns 1 and 4 are estimated with a linear polynomial on a sample of observations within the optimal bandwidth of 50 mm. Columns 2 and 5 are estimated with a linear polynomial on a sample of observations within an alternative bandwidth of 70 mm. Columns 3 and 6 are estimated using a quadratic polynomial on the entire sample.

Table 4: Total production at time $t + 1$

	(1)	(2)	(3)
Panel A: First Stage			
		payment = 1	
Below trigger	0.245***	0.235***	0.239***
	(0.0590)	(0.0768)	(0.0649)
Panel B: Reduced form			
		Δ log ha sowed (all)	
Below trigger	0.0704***	0.0663***	0.0479*
	(0.0231)	(0.0227)	(0.0240)
Panel C: 2SLS			
		Δ log ha sowed (all)	
% ha $\widehat{\text{receiving}}$ payment	0.288**	0.282*	0.200*
	(0.117)	(0.146)	(0.121)
Bandwidth	50	70	all
Polynomial	linear	linear	quadratic
N	1503	1947	3329

Note. Standard errors are clustered at the state level. Asterisks indicate statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Observations are at the municipality-year-level. Hectares sowed are defined as the total hectares growing any rainfed agricultural crop as reported in SAGARPA production data. Panel A shows results from the OLS estimation of the first stage, which corresponds to estimating equation 1. Panel B shows results from the OLS estimation of the reduced form, which corresponds to estimating equation 2, and panel C displays 2SLS estimates. Column 1 is estimated with a linear polynomial on a sample of observations within the optimal bandwidth of 50 mm. Column 2 is estimated with a linear polynomial on a sample of observations within an alternative bandwidth of 70 mm. Column 3 is estimated using a quadratic polynomial on the entire sample.

Table 5: Economic outcomes at time $t+1$

	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: First Stage						
	payment = 1					
Below trigger	0.341**	0.330**	0.351**			
	(0.121)	(0.117)	(0.143)			
Panel B: Reduced form						
	log expenditures p.c.			log income p.c.		
Below trigger	0.209	0.180	0.277*	0.290*	0.205	0.307*
	(0.140)	(0.126)	(0.138)	(0.165)	(0.153)	(0.153)
Panel C: 2SLS						
	log expenditures p.c.			log income p.c.		
% ha $\widehat{\text{receiving}}$ payment	0.613*	0.544*	0.789**	0.852**	0.622*	0.876**
	(0.333)	(0.314)	(0.356)	(0.361)	(0.369)	(0.353)
Bandwidth	50	70	all	50	70	all
Polynomial	linear	linear	quadratic	linear	linear	quadratic
N	2494	3538	5879	2494	3538	5879

Note. Standard errors are clustered at the state level. Asterisks indicate statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Observations are at the household-municipality-level. The treatment variables vary only at the municipal level. Panel A shows results from the OLS estimation of the first stage, which corresponds to estimating equation 1. Panel B shows results from the OLS estimation of the reduced form, which corresponds to estimating equation 2, and panel C displays 2SLS estimates. Columns 1 and 4 are estimated with a linear polynomial on a sample of observations within the optimal bandwidth of 50 mm. Columns 2 and 5 are estimated with a linear polynomial on a sample of observations within an alternative bandwidth of 70 mm. Columns 3 and 6 are estimated using a quadratic polynomial on the entire sample.

Table 6: Economic outcomes at time $t+1$ (cont'd)

	(1)	(2)	(3)
Panel A: First Stage			
		payment = 1	
Below trigger	0.341**	0.330**	0.351**
	(0.121)	(0.117)	(0.143)
Panel B: Reduced form			
		remittances > 0	
Below trigger	-0.117**	-0.0884**	-0.0821**
	(0.0468)	(0.0315)	(0.0327)
Panel C: 2SLS			
		remittances > 0	
% ha $\widehat{\text{receiving}}$ payment	-0.345*	-0.268*	-0.234
	(0.189)	(0.143)	(0.159)
Bandwidth	50	70	all
Polynomial	linear	linear	quadratic
N	2494	3538	5879

Note. Standard errors are clustered at the state level. Asterisks indicate statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Observations are at the household-municipality-level. The treatment variables vary only at the municipal level. Panel A shows results from the OLS estimation of the first stage, which corresponds to estimating equation 1. Panel B shows results from the OLS estimation of the reduced form, which corresponds to estimating equation 2, and panel C displays 2SLS estimates. Column 1 is estimated with a linear polynomial on a sample of observations within the optimal bandwidth of 50 mm. Column 2 is estimated with a linear polynomial on a sample of observations within an alternative bandwidth of 70 mm. Column 3 is estimated using a quadratic polynomial on the entire sample.

Table 7: Placebo: Agricultural outcomes Pre-CADENA

	(1)	(2)	(3)	(4)	(5)	(6)
		Δ log ha sowed			log yield	
Below trigger	0.000433	0.0104	0.0451	-0.0110	-0.0152	-0.0819*
	(0.0498)	(0.0304)	(0.0279)	(0.0596)	(0.0509)	(0.0425)
Bandwidth	50	70	all	50	70	all
Polynomial	linear	linear	quadratic	linear	linear	quadratic
N	3047	4425	13962	3047	4425	13962

Note. Standard errors are clustered at the state level. Asterisks indicate statistical significance: * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Observations are at the municipality-crop-year-level and are restricted to pre-CADENA years for each municipality. Agricultural production is for the corresponding insurable crop (maize, beans, sorghum, and barley). All regressions include crop fixed effects. Columns 1 and 4 are estimated with a linear polynomial on a sample of observations within the optimal bandwidth of 50 mm. Columns 2 and 5 are estimated with a linear polynomial on a sample of observations within an alternative bandwidth of 70 mm. Columns 3 and 6 are estimated using a quadratic polynomial on the entire sample.

Table 8: Weather index insurance costs and payments

(1) Year (MXN 000)	(2) Amount Insured (MXN 000)	(3) Premium Payments (MXN 000)	(4) Indemnity Payments (MXN 000)	(5) Loss Ratio - (4)/(3) (%)
2005	662,017	100,900	105,084	104
2006	874,768	103,032	21,529	21
2007	913,875	116,196	40,426	35
2008	1,456,329	239,549	84,509	35
2009	1,516,464	215,372	216,490	101
2010	1,202,618	240,493	217,220	90
2011	1,980,761	424,359	406,930	96
2012	1,567,581	422,666	105,472	25
2013	1,828,452	468,743	150,033	32

Note. Figures are calculated from policy data for all weather index policies. Amounts are in thousands of Mexican Pesos. The loss ratio in column 5 is calculated as indemnity payments (column 4) divided by premium payments (column 3).

10 Appendix

Table 9: Municipality summary statistics

Variable	All municipalities	ENIGH municipalities	p-value
Population	50,115.3	102,765.5	0.0
Years of education	6.8	7.0	0.1
% Illiterate	13.3	12.3	0.1
% No running water	16.5	16.7	0.9
% Dirt floor	8.8	8.9	0.9
% Indigenous population	11.5	10.9	0.8
Female % of employed pop	25.7	25.8	0.9
Male % of employed pop	74.3	74.2	0.9

Note. The data used to created this table comes from the 2010 census. % Illiterate is defined as the number of illiterate individuals over the age of 15 divide by the total population over 15.

Table 10: Weather index insurance loss ratio by state

State	Loss Ratio (%)			
	2005-2013	2005	2009	2011
Aguascalientes	2	0	20	0
Campeche	0	0	0	0
Chiapas	82	0	0	161
Chihuahua	1	0	0	9
Colima	0	0	0	0
Durango	10	0	12	11
Guanajuato	59	94	363	75
Guerrero	36	277	119	38
Hidalgo	40	151	0	0
Jalisco	68	34	16	100
Mexico	98	498	3	242
Michoacan	46	333	79	35
Morelos	41	0	0	0
Nayarit	165	0	0	309
Nuevo Leon	0	0	0	0
Oaxaca	74	0	73	80
Puebla	44	58	122	55
Queretaro	14	0	0	5
Quintana Roo	276	0	0	0
San Luis Potosi	81	0	41	305
Sinaloa	98	159	0	258
Sonora	0	0	0	0
Tabasco	113	0	147	0
Tamaulipas	125	0	232	51
Tlaxcala	12	22	79	0
Veracruz	48	0	10	36
Yucatan	0	0	0	0
Zacatecas	53	68	89	273

Note. Figures are calculated from policy data for all weather index policies. The loss ratio is calculated as as indemnity payments divided by premium payments.