THEMA
théorie économique, modélisation et applications

THEMA Working Paper n°2021-07
CY Cergy Paris Université, France

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February 2021

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February 8, 2021

Abstract

While there is a growing literature on the impact of climate and weather-related events on migration, little is known about the mitigating effect of different policies directed to the agricultural sector, or aimed at insuring against environmental disasters. This paper uses state-level data on migration flows between Mexico and the U.S. from 1999 to 2012 to investigate the migration response to weather shocks and the mitigating impact of an agricultural cash-transfer program (PROCAMPO) and a disaster fund (Fonden). We find that Fonden decreases migration in response to heavy rainfall, hurricanes and droughts. Increases in PROCAMPO amounts paid to small producers are found to play an additional, though more limited, role in limiting the migration response to shocks. Changes in the distribution of PROCAMPO favoring more vulnerable producers in the non irrigated *ejido* sector also seem to mitigate the impact of droughts on migration.

Keywords : International migration ; Weather shocks ; Public policies; Weather variability; Natural disasters ; Mexico-U.S. migration; Inequality

JEL classification : F22; Q54; Q18 ; 015; J61

*We are grateful to Pierre André, Lisa Anouliès, Simone Bertoli, Jose de Sousa, Alejandro del Valle, Salvatore Di Falco, Élise Huillery, Miren Lafourcade, François Libois, David McKenzie, Karen Macours, Marion Mercier, Katrin Millock, Ilan Noy, Hillel Rapoport, Ilse Ruyssen, Jean-Noël Senne, Ahmed Tritah, Michele Tuccio and participants to several seminars and workshops for helpful comments and suggestions. We thank François Libois for sharing with us the TRMM satellite rainfall data. We also thank Iván Tzintzun for excellent research assistance. This research has been conducted as part of the project Labex MMEDII (ANR11-LBX-0023-01) and has received financial support from CEPREMAP.

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1 Introduction

Among the many consequences of weather shocks and climate on economic activity, its impact on human mobility is a key issue. Together with weather-related disasters, gradual and sustained shifts in rainfall and temperatures also contribute to drive migration, in particular through their impact on agricultural yields (Schlenker and Roberts, 2009; Feng et al., 2012). Unsurprisingly, the impact of weather shocks and variability on migration is found to be larger in developing countries that are ex-ante more vulnerable (Beine and Parsons, 2015; Coniglio and Pesce, 2015). This result can be partly explained by the limited capacity of governments to fund public policies helping households to face adverse shocks. It thus seems crucial to assess the potential mitigating role of different types of pre-existing public policies that were not specifically designed to help people cope with climate variations. This article addresses the mitigating role of public policies which, though critical, has remained largely unexplored in the rapidly growing body of literature concerned by the impact of climate on migration [1].

Taking advantage of a unique panel database on yearly Mexico-US migrant flows at the Mexican state level from 1999 to 2012, this paper investigates the impact of weather-related factors on migration and the mitigating impact of two public programs, the cash-transfer agricultural program PROCAMPO, and the disaster fund Fonden. Migration flow data are constructed based on individual data from the Survey of Migration at the Northern Border of Mexico (*Encuesta sobre Migración en la Frontera Norte de México* or EMIF Norte). Information on Mexican states of origin and survey weights are used to obtain yearly migration outflows from each Mexican state. In spite of the unusual design of the EMIF aimed at capturing transit migrants, the data collected, once aggregated, have been found to be fairly representative of Mexico-US migrant flows (Rendall et al., 2009)[2]. Three major advantages of the migration flow data constructed from the EMIF

[1] Although our paper studies the effect of weather shocks, Hsiang (2016) refreshes the debate over the misuse of climate for weather by providing theoretical justifications to the use of weather variable to analyse the effect of climate.

[2] See also Chort and De La Rupelle (2016) for a detailed discussion of the advantages and drawbacks

are the availability of a 13 year panel, the fine level of regional disaggregation, and the possibility to analyze documented and undocumented flows separately[3].

We merge migration flow data to satellite and land data on precipitations and temperatures, and to data on hurricanes at the federated state level.To analyze the role of public policies, we combine migration and weather data with information on state-level payments of two governmental programs, the PROCAMPO program run by the Mexican Ministry of Agriculture (SAGARPA), and the disaster fund Fonden. The two programs, though of very different nature, are of particular relevance to our study. PROCAMPO is the largest agricultural program funded by the Mexican federal government and consists in direct payments to agricultural producers on a per-hectare basis made twice a year, while Fonden is a disaster fund aimed at providing insurance to localities hit by a natural disaster. The specificities of each program imply that they may have a different mitigating impact. Previous research has established that PROCAMPO subsidies have contributed to increase income inequalities in Mexico (Martínez González et al., 2017). For this reason, we investigate not only the effect of total amounts of PROCAMPO, but also distributional issues in the allocation of transfers.

We estimate OLS regressions using panel data over 1999-2012 on state-level Mexico-US migration flows with state and year fixed effects, standard errors being corrected for serial and spatial correlation (Hsiang, 2010). Identification relies on the assumption that changes in amounts - or distribution - of transfers received under the two programs are not caused by changes in migration patterns.We believe Fonden to be arguably exogenous enough to migration trends. Indeed, the disbursement of Fonden funds requires a declaration by the municipality which has experienced a natural disaster, as defined by Fonden operating rules, and the visit of a federal damage assessment committee. Moreover, municipality declarations are verified by a state agency based on objective data (overrun of a municipality-month specific daily rainfall threshold in the case of flooding),

of using the EMIF data to construct migration flow aggregates.

[3] Undocumented migrants are defined as individuals who declare having no document to cross the border nor to work in the US (see also the data section).

which leaves apparently no room for manipulation, as assessed by del Valle et al. (2020). However, past migration, in particular through remittances, could affect the capacity of Mexican states to face adverse weather shocks, and thus be correlated with Fonden support. Differences in migration history to the U.S. are captured by state fixed-effects, but year-to-year variations in migration flows correlate with financial transfers to home communities and may also modify their vulnerability to shocks. We show however that once controlling for weather shocks, amounts of Fonden funds received are uncorrelated to lagged migration flows. As for PROCAMPO, amounts per hectare are defined at the federal level and the set of eligible plots has been established in the 1990s. Following two waves of reforms in the 2000s increasing the amount received for plots below a particular threshold, strategic manipulation of plot size declared by producers and corruption arrangements may raise endogeneity concerns. To address this issue, we consider the set of all plots eligible in 1999[4] and their characteristics, before any reform took place, and apply to them the national variations in PROCAMPO payments which followed in the subsequent years. Moreover, we exploit discontinuity in PROCAMPO payments per hectare around plot size thresholds entitling to a bonus per hectare payment, to ensure that we are not capturing different characteristics of states related to land size distribution, which may also affect migration trends.

We find that undocumented Mexico-U.S. migration is sensitive to different types of weather shocks in Mexico, including hurricanes and droughts, consistent with previous studies in the same or comparable contexts (Munshi, 2003; Pugatch and Yang, 2011; Chort, 2014; Chort and De La Rupelle, 2016; Baez et al., 2017b,a). However, we provide evidence of the mitigating impact of the disaster fund Fonden. The response to adverse weather shocks (heavy rainfall, hurricanes, droughts) is reduced when Fonden amounts increase, especially for undocumented flows. A similar mitigating effect is found for PROCAMPO after negative rainfall shocks during the rainy season. In addition, an increased share of PROCAMPO transfers to the most vulnerable producers is found to limit

[4] We use the universe of PROCAMPO claims in 1999 for each state.

weather-induced migration. We test the robustness of our results using the grouped fixed effect estimator developed by Bonhomme and Manresa (2015) which allows to control for time-varying unobserved heterogeneity patterns shared by groups of observations.

This study contributes to the growing body of literature concerned with the impact of climate and weather shocks on migration, by exploring the mitigating role of public policies. In the context of Mexico, a number of previous papers have incidentally stressed the role of climatic events on migration (Munshi (2003), Pugatch and Yang (2011), Chort (2014), Chort and De La Rupelle (2016)). However, to date, few empirical studies have specifically focused on the impact of environmental factors on Mexican migration. Exceptions are Feng et al. (2010), who estimate the impact of decreases in crop yields due to climate change on migration, based on state level data for the periods 1995-2000 and 2000-2005. Saldaña-Zorrilla and Sandberg (2009) use data from the 1990 and 2000 Mexican censuses and focus on the impact of natural disasters on international migration. Nawrotzki et al. (2013) investigate the role of drought on migration based on the 2000 Mexican census[5]. The contribution of our paper to this literature is twofold. First, we complement existing evidence on climate induced Mexico-US migration by exploiting longitudinal yearly data on a relatively long period and by analyzing separately documented and undocumented flows. Second and most importantly, while previous studies exclusively focused on the effect of weather shocks, we investigate and compare the potential mitigating impact of different public policies.

Second, our paper relates to previous research that has analyzed the impact of public policies on migration. In the Mexican context, many studies have focused on the large anti-poverty PROGRESA/*Oportunidades* program. Early evaluations of PROGRESA suggest that conditional cash-transfers reduce migration to the U.S. (Stecklov et al., 2005). Focusing on labor migration only, Angelucci (2015) finds that entitlement to the new version of the PROGRESA program (*Oportunidades*) increases migration, suggestive

[5] All these issues are also conceptually discussed in Cohen et al. (2013) but without econometric validation, while Eakin (2005) uses ethnographic data to analyze the vulnerability of rural households to climatic hazards.

of the existence of credit constraints and consistent with Rubalcava and Teruel (2006). These conflicting findings indicate that the same program may have heterogenous impacts on migration depending on the use that is made of transfers received. Comparing the effect of PROCAMPO and Fonden, we find that both programs tend to mitigate the impact of shocks, however the mitigating impact of Fonden tends to be larger. Moreover, the two programs tend to affect mostly undocumented migration, suggesting that documented migration has different motives and is not sensitive to the same incentives.

More generally, this paper contributes to the literature on the mitigating role of public policies after a shock. The evaluation of the economic impact of the Fonden fund provided by del Valle et al. (2020) shows a positive and sustained effect of the program on local economic activity and employment, implying that Fonden may affect migration responses to climatic shocks through different channels. Previous works on PROCAMPO suggest that a basic cash-transfer program may also help its beneficiaries to cope with adverse economic shocks. Sadoulet et al. (2001) find an income multiplier of 1.5-2.6 for PROCAMPO beneficiaries in the *ejido* sector[6], which indicates that the transfers received under the program contribute to alleviating households' liquidity constraints. As such, PROCAMPO payments may affect the capacity of households to manage the effect of climatic shocks and influence migration decisions.

The rest of the paper is organized as follows: Section 2 first describes the Mexican context and the characteristics of the PROCAMPO and Fonden programs, and then presents the main mechanisms. The different data sources and construction are described in Section 3. Section 4 presents the empirical model, and results are presented and discussed in Section 5. Section 6 concludes.

[6]The *ejido* sector characterizes communal land created by the land reform following the 1910 revolution. Members of agrarian communities were allocated land use rights, provided that they would not leave land uncultivated for more than two years.

2 Context and policies

2.1 Climate and migration in Mexico

Studying the consequences of weather variability on migration in the Mexican context is particularly interesting for three reasons. First Mexico sits astride the Tropic of Cancer and has a large diversity of climatic characteristics, although almost all parts of the country are subject to hurricanes and tropical storms in summer and autumn[7]. Second, the economy of Mexican rural areas largely depends on agricultural activities[8]. Third, Mexico has a long history of migration to the United States, suggesting that moving has long been a way for Mexican households to cope with adverse economic shocks.

Climate projections for Mexico converge towards a 2.5 to 4°C increase in temperatures and a decrease in precipitations by 2100 (Gosling et al., 2011). Projections regarding extreme phenomena such as hurricanes are less clear-cut: some studies suggest that hurricanes may become more frequent and violent (Emanuel, 2013; Mendelsohn et al., 2012), but the impact of global warming on hurricanes is disputed. Although climate change is a long term phenomenon, focusing on weather shocks in the recent period is of relevance given the dramatic acceleration of global warming in the last two decades and the observed higher frequency of natural disasters such as hurricanes or floods.

2.2 The PROCAMPO and Fonden programs

We focus in this paper on two major programs, an agricultural cash-transfer program, PROCAMPO, and a disaster fund, Fonden. The PROCAMPO program is the vastest agricultural program in Mexico, initially launched in 1993 to mitigate the impact of the

[7]The most recent destructive episodes in Mexico were due to Hurricanes Ingrid and Manuel in September 2013, with an estimated number of directly affected people of one million and over 190 deaths, and Hurricane Norbert in 2008 striking the North Western states of Mexico and causing 25 deaths and millions of damages.

[8]Although the share of agriculture in the Mexican GDP is low (3.5% in 2010-2014) agricultural employment represents 13 % of total employment and 21% of the population live in rural areas (World Development Indicators, The World Bank).

North American Free Trade Agreement (NAFTA) on Mexican producers by substituting direct cash payments to price support. Initially, eligibility was limited to plots planted in one of the nine identified basic crops (corn, beans, wheat, rice, sorghum, soybeans, cotton, safflower and barley) in the three year period preceding the implementation of the program. Eligible producers receive cash transfers on a per-hectare basis twice a year, for each growing season (Spring-Summer and Autumn-Winter). In an early evaluation of the program, Sadoulet et al. (2001) find a high multiplier for PROCAMPO transfers, consistent with the existence of liquidity constraints and suggesting that received amounts are massively invested by producers in agricultural inputs.

The program went through several reforms, the first one being the extension of the program to plots planted in any legal crop, as well as areas with livestock or under forestry exploitation (autumn-winter cycle 1995-96). Several pro-poor reforms were carried out, in 2001, 2002-2003 and 2009. Starting in 2001, rainfed plots smaller than one hectare cultivated in the Spring Summer cycle received a payment corresponding to one full hectare. The 2002-2003 reform increased in particular the amount per hectare received by small producers. In 2003, the rainfed plots cultivated in the Spring-Summer cycle were entitled to an increased amount, called *cuota preferente*, if their area was under 5 hectares. This increased amount was then revaluated each year, in 2004 and 2005. In 11 states of the North [9], where land is dryer and rainfed plots are larger, the threshold was higher (from 6 hectares in Aguascalientes to 18 hectares in Baja California). The 2009 reform established a maximum amount of one hundred thousand pesos per beneficiary and agricultural cycle and increased the amount received by small non-irrigated plots in the spring cycle (Fox and Haight, 2010)[10]. The threshold for small plots was at the same time set to 5 hectares in all Mexican States. While average payments in real terms tend to decline over the period, the different pro-poor reforms contributed to maintain

[9] Aguascalientes, Baja California, Baja California Sur, Colima, Chihuahua, Durango, Jalisco, Sinaloa, Sonora, Tamaulipas and Zacatecas.

[10] Rainfed plots of less than 5 hectares cultivated in the Spring Summer cycle benefited from an additional increase, the *cuota allianza*. The amount received jumped from MXN 1160 to MXN 1300 per hectare.

the level of transfers to small producers (less than 5 ha) to around MXN 600 in constant 1994 prices[11]. Although PROCAMPO benefits are totally unrelated to climate events, this program is interesting because it is directed at agriculture, which is expected to be particularly affected by climate shocks. The coverage of the program is high, as the number of beneficiaries of PROCAMPO was 2,471,802 in 2010, representing 63% of agricultural production units. However the population of beneficiaries of PROCAMPO is highly heterogeneous, ranging from large producers cultivating irrigated land in the Northern part of the country to small farmers cultivating rainfed crops on a few hectares, mostly found in the *ejido* sector which represents 56% of Mexican agricultural land. The *ejido* sector has been associated with economic under-development ; besides limited property rights, it has also been plagued with the historical legacy of the 16th century demographic population collapse, including coercive institutions and rampant corruption (Sellars and Alix-Garcia, 2018). The *ejido* sector has undergone several changes in the 1990s leading to more individual control over *ejido* land, including a titling program initiated in 1993. Such reforms have been found to contribute to increasing migration flows to the U.S. (de Janvry et al., 2015; Valsecchi, 2014).

The second program, Fonden, is a disaster fund created in 1996 and operational only since 2000, aimed at providing emergency relief funds and financial support to municipalities hit by a natural disaster to fund reconstruction of federal and local government assets (World Bank, 2012; del Valle et al., 2020). Following an adverse shock, the procedure is launched with a declaration of a natural disaster and is subject to the decision of a damage assessment committee. The list of natural events qualifying for the program is not closed and includes in particular the following hydro-meteorological events: severe hail, hurricane, river flooding, rain flooding, severe rain, severe snow, severe drought, tropical storm, tornado. Since the start of the program, an average of 30 declarations of natural disasters has been registered each year. An evaluation of the impact of the program on economic recovery is provided by del Valle et al. (2020) who find a positive and sustained

[11] About USD 100 in 2010.

effect of Fonden on economic activity, associated with a large increase in employment in the construction sector. After a natural disaster, funds are delivered quickly (within days for emergency funds, to weeks or months for reconstruction funds). For this reason, in the following discussion and in the empirical analysis, we investigate the mitigating impact of the two programs (Fonden and PROCAMPO) on contemporaneous weather shocks.

Importantly, state-level funds received under both programs are unlikely to be directly correlated with ex-ante migration trends or, in the case of Fonden, anticipated by prospective migrants. Fonden is explicitly targeted at natural disasters that are unpredictable and exogenous to migration decisions. Although the list of natural disasters qualifying municipalities for application to Fonden is open, according to del Valle et al. (2020) who have access to disaggregated Fonden data, rainfall, flooding, and hurricanes represent 93% of the claims and over 95% of disbursed funds. A very strict verification process conditions the disbursement of Fonden benefits (del Valle, 2021), involving the validation of objective threshold overrun by a state agency based on observed physical parameters[12]. Nonetheless, concerns regarding a possible manipulation of Fonden rules by municipalities are taken seriously by del Valle et al. (2020). Based on municipality level data, they find no evidence of manipulation of rainfall statements by municipalities[13].

Regarding PROCAMPO, eligibility to the program is based on plots, not on farmers, and the set of eligible plots is expected to remain stable over the period. In particular, no new plots were to become eligible after 1996. Endogeneity issues regarding PROCAMPO may however arise if the implementation of the program allowed deviations to official rules, and if plot characteristics (size or irrigation type) were strategically manipulated, as evidenced by Martínez González et al. (2017). Second, a titling program, PROCEDE,

[12]Regarding hydro-meteorological events, the threshold is set to the percentile 90 of the maximum daily historic rainfall recorded at a representative weather station, and the verification of claims made by municipalities is devolved to Conagua, which is the national weather agency and does not make public neither the threshold, nor the subset of weather stations used to compute this threshold (del Valle et al., 2020).

[13]In particular, if rainfall declaration were manipulated, they would observe excess density at the right of the threshold. They formally test and reject this assumption based on the test statistic developed by Cattaneo et al. (2019).

aimed at the *ejido* sector, was ongoing until 2006, and could have resulted in changes in plot boundaries. Note however that the bulk of the program had been completed before our period of interest : 80% of *ejidos* had gone through the process in 2000 (de Janvry et al., 2015). To address potential endogeneity concerns regarding PROCAMPO, we construct, for each state and year, predicted measures of PROCAMPO transfers by combining the 1999 distribution of plot characteristics with the returns to those characteristics, defined at the federal state level and modified by several reforms over the period of our study. Predicted measures of PROCAMPO transfers thus depend only on nationwide changes in return to plot characteristics. In particular, state-level variations of PROCAMPO amounts, or changes in inequality measures of the distribution of PROCAMPO amounts, are driven by the state distribution of plots around the thresholds entitling to improved benefits in 1999, not by any strategic manipulation which could have followed the different reforms. The distribution of plot size for plots of less than 10 hectares is represented for each state in Figure 5, in Appendix. One might fear however that plot characteristics in 1999 may be correlated with migration trends. We address this issue, first, by including Mexican state fixed-effects, that account for the impact of state time-invariant characteristics, and second, by exploiting the discontinuity in theoretical payments around the threshold entitling to a bonus per hectare payment. We discuss further threats to our identification strategy in Section 4.2.

2.3 Expected effects and potential channels

We discuss in this section the impact of two different types of public programs on climate-induced migration : an unconditional cash-transfer program and a disaster fund that mimic the characteristics of the two programs PROCAMPO and Fonden. We have in mind a standard theoretical framework in which migration decision is taken based on a comparison of expected utilities and subject to liquidity or credit constraints. The latter assumption implies the existence of a pool of individuals willing to migrate but who are forced to stay for lack of sufficiently high income. Individual utility at home and abroad is expected to depend on local wage and amenities. We depart from Cattaneo and Peri (2016) and assume that weather shocks can affect both amenities, through the destruction of infrastructures for example, and wage at origin, by lowering productivity. Agricultural productivity is expected to be directly impacted by weather shocks, but productivity in non-agricultural sectors may also be negatively affected by adverse shocks (Hsiang, 2010). According to these two channels, a negative shock is expected to increase migration. A third effect goes in the opposite direction: through its impact on local wages, a negative climatic shock will reduce individual ability to fund migration costs and will tend to lower migration in case of credit or liquidity constraints. The resulting total impact of a negative weather shock on migration is indeterminate.

We now focus on the potentially mitigating effect of public policies by considering the impact of an unconditional agricultural cash transfer program[14], and a disaster fund, on the migration decision after a shock.

If the amounts received under the cash-transfer program are mostly invested in agricultural production, we expect the program to have a mitigating impact: following a negative shock, the program will help agricultural wage to recover and increase the utility of staying. Empirical evidence provided by Sadoulet et al. (2001) who focused on the *ejido* sector suggests that PROCAMPO transfers in the first years of the program were predominantly invested by producers in agricultural inputs. However, the transfer could also be used to fund migration. Provided that individual migration was initially subject to liquidity constraints, then the program would increase migration, consistent with the assumptions made by Angelucci (2015) for *Oportunidades*. The overall impact of the program on migration decisions in the event of a negative weather shock is thus indeterminate.

The disaster fund operates through different channels. Through Fonden, funds are

[14]Note that the operational rules and characteristics of PROCAMPO make it comparable to an unconditional cash-transfer program: provided that the migrant leaves at least one member of the household behind and that an agricultural activity is maintained, she retains her entitlement to the benefits of the program. However, as notes above, to avoid endogeneity issues we use predicted rather than actual amounts for PROCAMPO in our empirical analysis.

transferred to localities that suffered from a negative weather shock. Empirical evidence provided by del Valle et al. (2020) suggest that the transfers received by localities contribute to the reconstruction of infrastructures and generate a boom in the non-agricultural sector, due to the demand for labor created by reconstruction needs. We thus expect the disaster fund to provide incentives to stay by increasing the value of the home option, through its effect on amenities and on income, and thus to have a mitigating impact on migration.

Undocumented *versus* documented migrants

Documented migrants are likely to differ from undocumented ones along many dimensions, and in particular as regards their networks: documented migrants are likely to rely on stronger networks at destination than undocumented ones. Indeed, family reunification has been by far the primary motive for obtaining a legal residence permit in the U.S (Hanson, 2006). In the EMIF data, family reunification is the main reason given by surveyed individuals who declare having legal documents to cross the border.

Migration cost is expected to depend negatively on the size and strength of networks at destination. This suggests that migration costs could be cheaper for candidates to emigration being able to migrate with legal documents. All else equal, an increase in PROCAMPO transfers after a negative shock would thus increase undocumented migration more than documented migration as undocumented migrants may have a tighter budget constraint.

On the other hand, thanks to their stronger networks, potential documented migrants may receive greater amounts of remittances that would play an insurance role against negative shocks, including weather shocks. As a consequence, post-shock income depends more crucially on PROCAMPO amounts for potential undocumented migrants. The mitigating effect of PROCAMPO should thus be larger on undocumented migration flows than on documented ones. Considering both propositions together, the difference in the response of documented and undocumented migration to an increase in PROCAMPO transfers after a shock is unclear, and depends on the use that is made of PROCAMPO amounts. If, as suggested by Sadoulet et al. (2001), amounts received are mostly invested in agricultural inputs, then the mitigating impact of PROCAMPO should prevail. Moreover, small producers in the *ejido* sector are more vulnerable and probably more responsive to PROCAMPO amounts. In that respect, any change in the distributional patterns of PROCAMPO beneficial to the *ejido* sector should result in a larger mitigating impact on undocumented flows.

As for Fonden, the main effect of the disaster fund is to increase the value of the home option. Given that candidates to undocumented migration are expected to be provided less insurance by their networks, they are also expected to be more sensitive to an increase in Fonden than documented migrants.

In sum, while the effect of the unconditional agricultural cash-transfer program on migration in response to a negative weather shock is indeterminate, the disaster fund is expected to have an unambiguous mitigating effect, especially for undocumented migrants. Given the characteristics of the two programs studied here, we expect the impact of PROCAMPO on climate-induced migration to depend on the use that is made of cash-transfers received, while Fonden is likely to reduce migration, especially undocumented flows, in response to an adverse shock.

3 Data

3.1 Migration flows

Migration flow data are constructed from the EMIF surveys (Encuesta sobre Migración en la Frontera Norte de México)[15], collected annually since 1993 at the Mexico-US border. The EMIF aims at providing a representative picture of migration flows between Mexico and the US, in both directions. Individuals in transit are screened at several survey points along the border which are regularly updated to account for changes in geographical pat-

[15] http://www.colef.net/emif/

terns and border enforcement measures. Those identified as migrants are individually interviewed[16]. The representativeness of the EMIF data is assessed by Rendall et al. (2009) who conclude to the particularly good coverage of male flows and undocumented flows[17]. To further evaluate the geographic representativeness of the EMIF, we compare the weighted state-level migration data from the EMIF to migration data from the ENADID (*Encuesta Nacional de la Dinámica Demográfica*) (Instituto Nacional de Estadística and Geografía (Mexico) and Consejo Nacional de Población (Mexico), 2011). Table 3 in Appendix compares, for the top ten Mexican states of origin over the period 2004-2009, the shares of each state in total emigration flows according to the two data sources (EMIF and ENADID). Rankings and contributions of most states are very similar in both cases, with the notable exception of Chiapas. Indeed, Chiapas appears as a major state of origin in the EMIF whereas its contribution to total emigration flows is much lower according to the ENADID. However, studies pointing to the incredibly high amount of remittances received by Chiapas with regard to its number of international migrants (as measured by traditional household surveys) tend to suggest that the data from the EMIF provide a more accurate estimate of the actual size of migration flows from Chiapas (Solís and Aguilar, 2006).

Using the survey sampling weights, and information on the state of origin of surveyed migrants, we construct a database of yearly migration flows for the 31 Mexican states of origin plus the Federal district. The migration database used in this article exploits 14 waves of the EMIF survey that could be matched with climatic data covering the 1999-2012 period[18]. We focus on male flows, since according to Rendall et al. (2009) the EMIF tends to under-represent migrant women. Using information collected in the survey, we are able to identify documented and undocumented migrants, and thus to separately

[16]The survey design is described in detail in each yearly report provided by the EMIF team, available at: `http://www.colef.mx/emif/publicacionesnte.php` and additional information on the survey design and the computation of the sampling weights are provided on the website of the EMIF (`http://www.colef.net/emif/diseniometodologico.php`).

[17]The advantages and drawbacks of using the EMIF data to analyze Mexico-US migration flows are also extensively discussed in Chort and De La Rupelle (2016)

[18]Fonden data being available since 2000, our main model is estimated over the period 2001-2012

analyze documented and undocumented migration flows. We define as undocumented migrants individuals who declare having no document to cross the border nor to work in the US.

Descriptive statistics are provided in Table 4. Male migrants account for 0.5% on average of the total population of their state of origin and most of them (64% on average over 1999-2012) are undocumented.

3.2 Weather shocks, economic variables, and public programs

We use satellite data from the "Tropical Rainfall Measuring Mission" (TRMM) and monthly gridded time series provided by the Department of Geography of the University of Delaware to construct state-level variables capturing deviations in precipitations and air temperatures from long-term averages. The TRMM is a joint project between the NASA and the Japanese Aerospace Exploration Agency which has been launched in 1997 to study tropical rainfalls, and is therefore well adapted to the Mexican context. Moreover, various technological innovations (including a precipitation radar, flying for the first time on an earth orbiting satellite) and the low flying altitude of the satellite increase the accuracy of the climatic measures. Interestingly enough, the TRMM products combine satellite measures with monthly terrestrial rain gauge data. Last, the measures are provided for 0.25 x 0.25 degree grid squares (around 25 km X 25 km), which allows us to construct very precise climatic variables[19]. We construct rainfall and temperature state-level variables for the two main meteorological seasons in Mexico, the rainy season (spanning from May to October) and the dry season[20]. Following Beine and Parsons (2015), we create state-level normalized rainfall and air temperature variables (z-scores). However, we construct those measures of weather anomalies at the seasonal level, as seasonal variables have been found to be more relevant and precise than yearly indicators

[19] Alternative measures of climate shocks such as the Palmer Drought Severity Index (PDSI) or the Standardized Precipitation-Evapotranspiration Index (SPEI) are less suitable to our analysis as their resolution is lower (2.5 x 2.5 degree for the PDSI, 0.5 x 0.5 degree for the SPEI).

[20] We also investigate the impact of yearly shocks, but find no significant effect on migration (results available upon request).

(Hsiang, 2010; Coniglio and Pesce, 2015) [21].

A description of the state-level variability of the constructed measures of weather anomalies is provided in figures 6 to 9 in Appendix. These graphs show that, within each state, we observe substantial variation in the different z-scores. To account for the potential damaging impact of tropical rainfall, and consistent with operating rules of Fonden disbursements, we complement these measures of weather variability with a variable capturing intense precipitation episodes at the infra-seasonal level. We use the number of months in the year with precipitations exceeding the 90th percentile of the long term distribution for each Mexican state. With this measure, we intend to construct a proxy for the threshold set by Fonden rules to claim funds after heavy rainfall, flooding and hurricanes.[22]

In addition, we construct a state-level data set of hurricanes affecting Mexico between 1999 and 2012, from the Historical Hurricane Track tool developed by the U.S. National Oceanic and Atmospheric Administration (NOAA)[23]. We gather information on the number and intensity of hurricanes and storms affecting each Mexican State and create two yearly state-level variables for the number of hurricanes and storms, and the maximum storm intensity registered in the year.

We have no variable allowing us to directly measure flooding, but flooding is potentially captured by several weather variables : excess rainfall, hurricanes, but also droughts,

[21] To construct seasonal z-scores, we first assign grid points to states based on latitude and longitude coordinates, then compute state-level total precipitations or average temperatures for each season, state-level long term seasonal averages and state-level seasonal standard deviations. Long term averages are obtained by combining the land and satellite data sources described above. The normalized variable is the state-level rainfall or temperature value minus the state-level long-run mean, divided by the state-level standard deviation over the observation period. For example, a positive value for the rainfall z-score for year t and season s in state i means that for year t, season s has been an especially rainy season in state i. Conversely, a negative value means that precipitations have been lower than (long-term) average in state i and season s of year t.

[22] Our heavy rainfall measure is constructed at the state level, based on the number of months where the state experienced rainfalls above the percentile 90 of monthly rainfalls. However, Fonden sets the threshold to the 90th percentile of maximum historic daily rainfall experienced by a municipality during the month when the event took place. We assume that our state level measure is correlated with heavy rainfalls experienced by municipalities, but we expect this proxy to be noisy. Typically, localized rainfalls will not be captured by our measure. This should downward bias the estimated impact of the disbursement of Fonden following heavy rainfall.

[23] http://www.csc.noaa.gov/hurricanes/

as dry soils facilitate water runoff even after moderate rainfall [24].

State level data on PROCAMPO payments were aggregated based on individual data provided by the Mexican ministry of agriculture (SAGARPA). Aggregate data on total annual amounts distributed at the state level under the Fonden program come from the open data Mexican government's website[25].

Additional data on income, population, agriculture and crime used to test the robustness of our main results to the inclusion of state-level controls come from the Mexican Instituto Nacional de Estadística y Geografía (INEGI)[26].

4 Empirical strategy

4.1 Estimated equation

In our main model, we estimate the effect of weather shocks and their interactions with public policies on migration. In Appendix, we report additional estimation results documenting the impact of weather shocks on migration with measures of weather shocks interacted with quartiles of agricultural production, and depending on the sign of the shock (see Table 12). All regressions are panel regressions with origin and year fixed-effects, and are estimated with OLS. As common or idiosyncratic unobserved characteristics of states may induce serial and spatial correlation or error terms, we provide non-parametric estimates of the variance of the coefficients following Conley and Ligon (2002)[27].

[24] We discuss further this mechanism below, in Section 5.

[25] `https://datos.gob.mx/`

[26] Some of our variables taken from the census, and in particular Mexican population at the state level, are linearly extrapolated for the years in which they are not available.

[27] The code for STATA developed by Hsiang (2010), based on Conley (1999) is available at `http://www.fight-entropy.com/2010/06/standard-error-adjustment-ols-for.html`. We modified it in order to account for fixed-effects and we corrected for the subsequent loss of degree of freedom. Parameters are estimated by OLS, and standard errors are corrected accounting for serial correlation over 1 period and for spatial correlation up to a distance cutoff set at 500 km. The cutoff has been chosen after examining the Moran's I index (for male migration rate) using different distance thresholds. Moran's I is significant up to a cutoff of 1600km, and decreases from 0.4 to 0.01 as the distance cutoff increases from 200 km to 1600 km, respectively. Small cutoffs might however reduce the number of observations impacted by the correction, given the size of some Mexican states. Interestingly, a jump is visible when considering a cutoff of 500 km (Moran's I amounts to 0.25) instead of 600 km (Moran's I amounts to 0.09). A cutoff of 500 km only excludes one state (Baja California, for which the distance to the closest

The estimated equation is the following:

$$MIGR_{i,t} = \beta_1 CLIM_{i,t-1,s} + \beta_2 CLIM_{i,t-1,s} \times POL_{i,t-1} + \beta_3 POL_{i,t-1} + D_i + D_t + \epsilon_{i,t}$$

with $MIGR_{i,t}$ the cube root of the migration rate from Mexican origin state i at time t (per 10,000 population), $CLIM_{i,t-1,s}$ a set of climatic variables measured in origin state i and season s of year $t-1$, and $POL_{i,t-1}$ represents either the state-level amounts distributed under Fonden or different measures of PROCAMPO amounts and their distribution. D_i and D_t are state and year fixed effects. To avoid endogeneity issues, we follow Dallmann and Millock (2016), Cai et al. (2016) and Cattaneo and Peri (2016), and choose not to include additional controls in our main specification. We test the robustness of our results when controlling for GDP per capita, unemployment rate, and the share of homicides, all of them with a lag of one period (see Table 9 in Appendix, discussed in Section 5.2).

We exploit the information contained in the micro-data used to construct aggregate flows to estimate the above equation for documented and undocumented flows separately.

For a relatively small number of observations, we observe zero total and/or undocumented flows (5 state-year cells for total flows representing 1% of observations, and 12 state-year cells for undocumented flows representing 2.5% of the total sample). As a high share of migrant flows are undocumented, the proportion of zero flows is larger for documented flows (9.5% of state-year observations). Zero cells are not expected to be qualitatively different from non-zero ones, but rather result from migration flows that are too small to be captured by the EMIF surveys. To deal with this issue, we use a cube root transformation of the dependent variable. We prefer the cube root transformation

neighboring state is higher than 500 km). 500 km is also the median value of the distance between the capital city of each state and Mexico city. All results are robust to allowing for autocorrelation over 2 periods and to a 800 km distance cutoff, representing the mean value of the distance between the capital cities of all pairs of Mexican states.

for three reasons. First, it allows us to retain zero-value observations in the estimation sample. Second, it does a better job than the log transformation to approximate a normal distribution (Schwartz, 1985)[28]. Third, it is easier to interpret than the hyperbolic inverse sine transformation, which also allows to retain zero value observation, but whose complexity is often overlooked (Bellemare and Wichman, 2020) [29].

However, our results are robust to using the inverse hyperbolic sine of the dependent variable (results shown in Table 7). Both transformations of the dependent variable allow us to estimate our model with OLS [30].

4.2 Identification issues

PROCAMPO

As discussed in Section 2.2, PROCAMPO variations, net of state fixed effect, are theoretically exogenous to migration. However, concerns regarding potentially endogenous changes in plot characteristics as well as biased measurement errors (if for instance the management of administrative data varies with political parties in power) could threaten our identification strategy. We thus use PROCAMPO plot level data on 36.9 million claims to compute an exogenous measure of transfers for each year and state using the 1999 distribution of characteristics in each state. We categorize all plots depending on the growing season, irrigation status, and total area cultivated by the producer. We then rely on administrative sources to retrieve the nation-wide evolution of per-hectare pay-

[28]For instance, the skewness of the cube root of the male migration rate is -0.009, while the skewness of the log of the male migration rate is -0.55 - it is obviously even more left-skewed after including the transformed zeros

[29] Indeed, if $Y^{\frac{1}{3}} = \alpha + \beta_X X + \epsilon$, then $\beta_X = \frac{\partial(Y^{\frac{1}{3}})}{\partial X} = \frac{\partial Y}{\partial X}\frac{1}{3Y^{\frac{2}{3}}} = \frac{\partial Y/Y}{\partial X}\frac{Y^{\frac{1}{3}}}{3}$. The interpretation is even simpler when $Y^{\frac{1}{3}}$ is close to 3: The coefficient can then be read as the percentage change in Y following a unitary increase of X. It makes sense in our case as the sample mean of the cube root of the male migration rate is 3.2 per 10 000 inhabitants (see table 4). Obtaining the semi-elasticity at other values of the migration rate is easy, as $\frac{\partial Y/Y}{\partial X} = \beta_X \frac{3}{Y^{\frac{1}{3}}}$

[30]Alternative methods may seem more adequate to dealing with zero values of the dependent variable, such as the Poisson pseudo-maximum likelihood (PPML) estimator. However, the advantages of the PPML estimator, limited given the relatively small proportion of zeros in our data, are outbalanced by the fact that it does not allow to correct for spatial and serial correlation of error terms.

ment. We combine this information with the distribution of plot characteristics in 1999, and then re-aggregate the obtained results at the state level. This provides us with state level variables for PROCAMPO amounts or distribution whose variation are exogenous to changes in plot characteristics. In what follows, these variables are labelled “predicted” PROCAMPO variables. Since we want to focus on the variations in PROCAMPO payments induced by the pro-poor part of the reforms, we construct a measure that considers only positive variations in amounts per hectare, which means that we focus on the bottom of the distribution of plot areas. Second, it is important to note that the variation in predicted PROCAMPO payments for a given state is driven by both the national reforms in the per-hectare amount and the distribution of plots around the relevant thresholds in 1999 (1 hectare and 5 hectares, for the bottom of the distribution which is of relevance to us). Since states with different distributions of plot size may have dissimilar migration trajectories, we exploit the discontinuity introduced by the nationally defined 5 hectare threshold that determines different per hectare payments. More specifically, we define our variable of interest as the state-level predicted amount of PROCAMPO payments - computed using plot size distribution in 1999 and subsequent evolutions of per hectare payments for plots under the 5 hectare threshold - theoretically paid to plots around this 5 hectare threshold. As noted above, the 5 hectare threshold holds for the majority of Mexican states, and for them, we consider amounts paid to plots between 4 and 6 hectares. For the 11 states from the Northern part of the country that benefited from an exemption from 2003 to 2009 and were assigned a different threshold conferring entitlement to a bonus payment, we consider amount paid to plots between 1 hectare below and 1 hectare above the threshold. With this definition of the PROCAMPO variable, we are rather confident that we are not capturing time-varying characteristics of Mexican states that could explain migration trends.

Fonden

We have already stressed that the disbursement of Fonden was arguably not manipulated by local governments, as established by del Valle et al. (2020) and del Valle (2021). The identification of the effect of the variable of interest, namely the interaction term between Fonden and weather related variables, requires that conditional on state fixed effect, year fixed effects, and control variables, effects on migration are linear. Even if Fonden is indexed on a running variable which cannot be manipulated, we do not limit our analysis to events occurring close by the threshold conditioning the disbursement of Fonden. Correctly identifying our effect of interest requires that the effect of Fonden should be similar for all municipalities, whatever their distance to the threshold: the effect should be likely to remain stable whatever the intensity of the experienced event.

del Valle et al. (2020) have assessed the external validity of their estimated effect for Fonden and found no evidence that the effect of Fonden was not stable or was likely to change considerably for lower or for heavier rainfall. Investigating the derivative of Fonden treatment effect, they have shown that it was locally constant. They have thus provided evidence that in municipalities which are away from the threshold and experience much lower or much higher rainfall, Fonden was likely to have effects of similar magnitudes on their outcome of interest. Even though their outcome variable (night lights) is different from ours, their findings support the hypothesis that the effect of Fonden would not have been substantially different for different shock intensity.

Additionally, we need to ensure that the effect of the different weather variables on migration is relatively linear, conditional on other control variables which include weather events of various intensities , so that their estimated effect in places where Fonden was not disbursed correctly control for their expected impacts in places where Fonden has been disbursed. To check that this is the case, we add to the sample the years 1999 and 2000, prior to the creation of Fonden, for which the impact of intense weather shocks can be observed in the absence of Fonden. Reassuringly, results are unaffected (see Table 6, in Appendix).

As noted in the introduction, past migration, in particular through remittances, could have an indirect role on the impact of disasters, and may thus be correlated to amounts of Fonden received. Indeed, remittances are expected to increase the capacity of communities to face adverse shocks. In that case, past migration would limit the need for Fonden support. In our regressions, differences in migration history to the U.S., as well as historical migrant networks, are captured by Mexican state fixed-effects. However, year-to-year variations in migration flows may affect financial transfers to home communities and thus modify their vulnerability to shocks. To test this assumption, we regress the (cube root) amount of Fonden received in t on migration flows in $t-1$, controlling for lagged and contemporaneous weather shock variables. Results are reported in Table 5 in Appendix. Reassuringly, they show no significant correlation between lagged migration and Fonden amounts.

5 Results

5.1 Mitigating impact of public policies

In Table 1, we explore the effects of the two public programs presented in Section 2, PROCAMPO and Fonden, on climate-driven migration. Regarding PROCAMPO, our variable of interest is the log predicted amount paid to plots around (+/- 1 hectare) the national threshold conferring entitlement to an increased per hectare payment.

The Fonden program being a disaster fund, amounts received are conditioned upon the occurrence of a shock. As a consequence, the proportion of state-year cells with zero registered amounts is high. We choose to consider the cube root of the yearly per capita amounts received, but our results are robust to alternative choices[31].

Columns (1), (3), and (5) of Table 1 show regression estimates with interactions

[31] Our results are qualitatively unchanged when taking the log of Fonden amounts (per capita) to which we add 0.01 (which is lower than the lowest observed value for the variable in the sample). Results are shown in Table 8.

Table 1: Climatic factors and Mexico-US migration flows : impact of public policies, 2001-2011

Cube root dependent variable	Total male flows (1)	(2)	Documented male flows (3)	(4)	Undocumented male flows (5)	(6)
Log PROCAMPO around the threshold (+- 1ha) $_{t-1}$	-0.070	-0.035	0.171	0.213	-0.236	-0.215
	(0.18)	(0.18)	(0.18)	(0.18)	(0.15)	(0.16)
Cube root amt Fonden $_{t-1}$	0.042***	0.048**	0.050***	0.067**	0.008	-0.000
	(0.01)	(0.02)	(0.02)	(0.03)	(0.01)	(0.02)
Hurricane in $_{t-1}$	0.572	0.327**	-1.217	0.139	0.005	0.133
	(1.16)	(0.16)	(1.64)	(0.21)	(1.16)	(0.12)
Hurricane max intensity $_{t-1}$	-0.078*	-0.069	-0.054	-0.074	-0.017	0.001
	(0.04)	(0.05)	(0.06)	(0.06)	(0.04)	(0.04)
Nb months rain >90th ptile $_{t-1}$	-0.493	0.012	-0.556	0.077*	-0.039	-0.012
	(0.43)	(0.05)	(0.48)	(0.05)	(0.46)	(0.05)
Rain deviation rainy s. $_{t-1}$	-1.006**	-0.064	-0.017	-0.134**	-0.493	-0.044
	(0.46)	(0.06)	(0.53)	(0.06)	(0.50)	(0.06)
Rain deviation dry s. $_{t-1}$	-0.547	-0.137***	0.615	-0.031	-1.013	-0.117**
	(0.48)	(0.04)	(0.56)	(0.05)	(0.62)	(0.05)
Temp deviation rainy s. $_{t-1}$	-0.350	0.113	0.528	0.078	0.009	0.023
	(0.53)	(0.07)	(0.51)	(0.07)	(0.60)	(0.05)
Temp deviation dry s. $_{t-1}$	-0.590	-0.094	0.333	-0.119	-0.901	-0.011
	(0.57)	(0.07)	(0.64)	(0.08)	(0.62)	(0.05)
Hurricane in $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	-0.018		0.077		0.002	
	(0.07)		(0.09)		(0.06)	
Nb months rain >90th ptile $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.026		0.032		0.001	
	(0.02)		(0.03)		(0.03)	
Rain deviation rainy s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.056**		-0.004		0.028	
	(0.03)		(0.03)		(0.03)	
Rain deviation dry s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.028		-0.034		0.055	
	(0.03)		(0.03)		(0.03)	
Temp deviation rainy s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.028		-0.024		0.002	
	(0.03)		(0.03)		(0.03)	
Temp deviation dry s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.030		-0.026		0.052	
	(0.03)		(0.03)		(0.03)	
Hurricane in $_{t-1}$ XCube root Fonden $_{t-1}$		-0.043		0.014		-0.052**
		(0.03)		(0.04)		(0.03)
Nb months rain >90th ptile $_{t-1}$ XCube root Fonden $_{t-1}$		-0.015		-0.028**		-0.002
		(0.01)		(0.01)		(0.01)
Rain deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.018		0.020*		0.015
		(0.01)		(0.01)		(0.01)
Rain deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.031***		0.013		0.028***
		(0.01)		(0.01)		(0.01)
Temp deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.013		0.019		0.008
		(0.01)		(0.02)		(0.01)
Temp deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.014		0.001		0.010
		(0.01)		(0.01)		(0.01)
N	384	384	384	384	384	384

Standard errors corrected for autocorrelation and spatial correlation in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

between weather variables and PROCAMPO, for total, documented, and undocumented flows respectively. Column (1) suggests that an increase in PROCAMPO amounts has a mitigating effect for rainfall during the rainy season. Indeed, the coefficient on the rainfall z-score during the rainy season is negative and significant at the 5 percent level, while the coefficient on the interaction between the same weather variable and PROCAMPO is positive and significant. Tables Table 12, column (6), in Appendix B, helps us to interpret this result, as the impact of rainfall shocks during the rainy season appears to be driven by negative rainfall shocks, which are found to increase migration. Thus, an increase in PROCAMPO amounts around the 5 hectare threshold is found to limit the increase in migration to the U.S. following negative rainfall shocks during the rainy season. In line with the discussion about the expected effects and channels of different policies in Section 2.3, the mitigating impact of the PROCAMPO suggests that PROCAMPO funds are invested rather than used to fund migration after a negative rainfall shock. This finding is also consistent with the survey data used in Sadoulet et al. (2001), according to which 70% of farmers in *ejidos* use PROCAMPO funds to buy agricultural inputs.

Columns (2), (4), and (6) of Table 1 report regression results for Fonden, on total, documented and undocumented migrant flows. As shown in column (6), the interaction of the measures of weather shocks with Fonden suggests a mitigating effect of the Fonden program, especially for undocumented flows: a concurrent increase in the Fonden variable limits or even outbalances the effect of a hurricane or a drought. Similar to what is observed for rainfall during the rainy season, note that the effect of deviations in rainfall during the dry season is driven by *negative* deviations (see Table 12, column (9), in Appendix B). The negative coefficient on the rain deviation variable for the dry season must be interpreted as a *positive* effect of droughts on migration flows. By contrast, the positive coefficient on the rain deviation variable interacted with Fonden suggests that Fonden *reduces* the undocumented migration response to negative rainfall shocks. A similar mitigating effect of Fonden is found for documented flows after (negative)[32] rainfall shocks during the rainy season.

We find consistent results for hurricanes on undocumented flows. The coefficient on the hurricane dummy is positive (although significant for total flows only, see column (2)), but the sign of the coefficient on the hurricane dummy interacted with Fonden is reversed for undocumented flows, pointing again to the mitigating effect of Fonden. In addition, evidence of a mitigating effect of Fonden is also found for the measure of

[32]see Table 12, column (6))

abnormal concentration of precipitations: a greater number of months in the year with rainfall above the 90th percentile tends to increase documented flows (column (4)), but the effect is alleviated by higher amounts of Fonden.

The mitigating effect of Fonden following abnormally low precipitations deserves further explanation. Indeed, the program is primarily intended at the reconstruction of damaged low-income housing and infrastructures (del Valle et al., 2020) and droughts are expected to have both a direct damaging impact on infrastructures through clay shrinkage, in particular on roads, buildings, and water and sewer lines (Corti et al., 2011; Combs, 2012), and a further indirect effect on infrastructures linked to wildfires or soil absorption capacity. With regard to the latter issue, droughts are likely to be correlated with flooding although we cannot directly measure such a correlation for lack of disaggregate data on the type of disasters on which Fonden amounts are spent. Water runoff are intensified after periods of drought because the water holding capacity of crusted soils is low (Horton, 1933). Experimental evidence in the case of Northern Mexico show that very small amounts of rainfall can cause Hortonian runoff (Descroix et al., 2007)[33]. As a consequence, normal rainfall may result in runoff and flooding with potential devastating consequences if they occur after a period of drought. Note that drought induced Hortonian runoff accelerate soil degradation, which in turn decreases the water holding capacity of soils. These different mechanisms may explain why we find a mitigating impact of Fonden during drier than average periods.

Fonden has a sizeable mitigating effect. Consider an average state, with 6 millions inhabitants, and 48 migrants per 10 000 inhabitants; among them, 33 are undocumented, and 15 are documented. An increase in Fonden amounts from 74 pesos per capita to 306 pesos per capita[34] decreases the migration response to weather events as follows: in case of a hurricane, the undocumented migration rate decreases by 3.3 points (per

[33] "Runoff can occur after 1 or 2 mm rainfall in crusted soils in the Western Sierra Madre" (Descroix et al., 2007), p.156.

[34] 74 pesos per capita is the sample mean of Fonden amount per capita. An increase of the cube root amount by 2.5 (the standard deviation) translates into an increase from 74 to 306 pesos per capita in the raw amount.

10 000 inhabitants); if there is an additional month with heavy rainfalls (*ie* above than the 90th historical percentile), the documented migration rates decreases by 1.2 points; and when rainfall during the dry season decreases by one standard deviation below the mean, the total migration rate decreases by 2.7 points. These are all non negligible effects (corresponding to 6% to 10% of the sample mean migration rate).

5.2 Group fixed-effects estimations and additional robustness checks

Economic and agroecological conditions differ across Mexican regions, and may influence both migration patterns and vulnerability or adaptation to shocks. For example, as explained in Section 2, 11 Mexican states from the Northern part of the country benefited from marginal adaptations of the PROCAMPO national rules due to their specific climatic and agricultural characteristics. In order to account for unobserved heterogeneity patterns shared by groups of states, we test the robustness of our main results by applying to the analysis of migration flows the estimator developed by Bonhomme and Manresa (2015). This estimator is particularly relevant to the empirical study of migration. While we might know the destination of migrants, we usually do not know all other alternative destinations they might have considered. These alternative destinations might be shared by groups of migrants, or group of states of origin in our analysis, who for instance have connected migration networks. As a result, groups of states sharing the same migration networks and thus the same pool of potential destinations, might both face similar shocks at origin and experience changes in their set of potential destinations. The latter change might thus be wrongly attributed to variations in the conditions at origin. Correcting for spatial autocorrelation is a first way of dealing with this issue, yet usual methods treat all units within a given perimeter in the same way, and assume time-invariant patterns of unobserved heterogeneity. This estimator allows group membership to be endogenously determined following a minimization criteria - groups are formed of states with similar time profile, net of the effects of the covariates included in the model.

We use the grouped fixed effects (GFE) estimator and replicate models from Table 1 with the number of groups varying from 2 to 7.

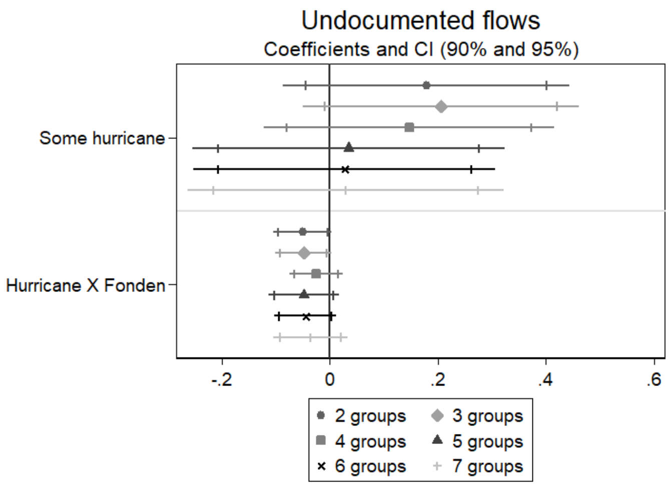

Figure 1: GFE coefficients for Fonden, undocumented flows

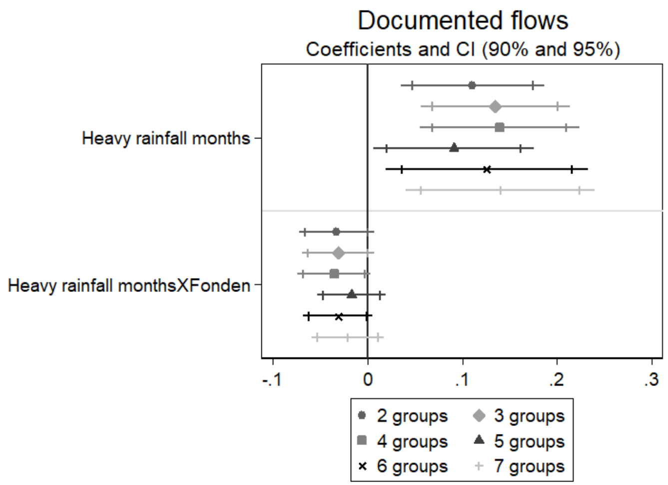

Figure 2: GFE coefficients for Fonden, documented flows

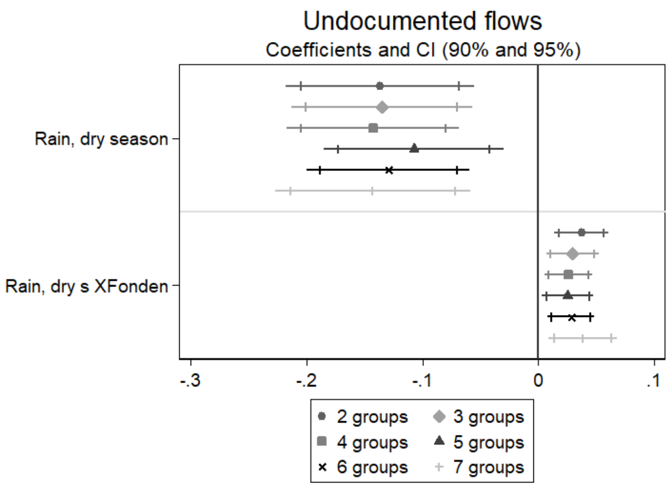

Figure 3: GFE coefficients for Fonden, undocumented flows

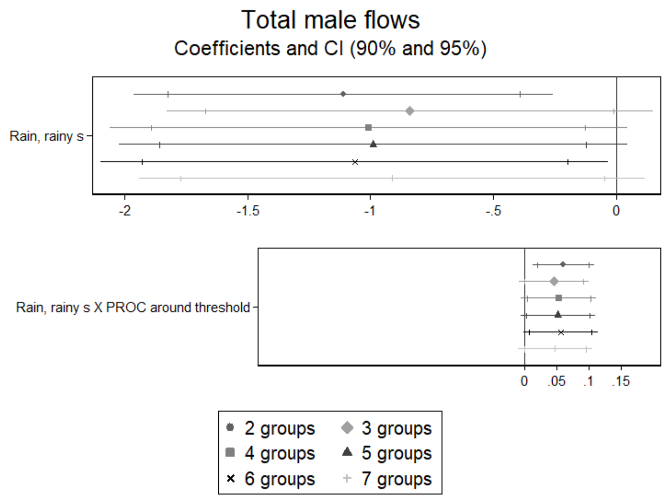

Figure 4: GFE coefficients for PROCAMPO (predicted share of PROCAMPO amounts to non-irrigated *ejido* land), undocumented flows

The figures display the coefficients estimated by the Grouped fixed-effect estimator, for different numbers of groups, and the confidence intervals at 90 and 95%, obtained after a blockbootstrap of 1000 replications.

Figures 1 to 4 display the coefficients obtained with the GFE estimator for the sub-samples and interactions of interest, namely the interactions between Fonden or PROCAMPO (predicted amounts around the 5 hectare threshold), and weather variables, depending on the number of groups. Standard errors are obtained after a blockbootstrap of 1000 replications. Graphs 1 to 4 show that, for Fonden and PROCAMPO both the size and significance of the coefficients are consistent with the results previously obtained, whatever the number of groups.

5.3 Additional robustness checks

We test the robustness or our results to using a hyperbolic inverse sine transformation of the dependent variables (Table 7 in Appendix) or to considering the Fonden variable in log rather than using a cube root transformation (Table 8 in Appendix). Additionally, we test the robustness of our main results to the inclusion of a set of economic and social controls (see Table 9 in Appendix). The mitigating effect of Fonden is confirmed in those different robustness tests. However, the coefficients on the interaction between PROCAMPO amounts and the shock variables are no longer significant when controlling for lagged economic and social variables measured in Mexican states of origin (GDP per capita[35], unemployment rate, and the rate of homicides). In addition, our results are robust to dropping observations for the year 2010 in order to remove the effect of the exceptional drought of 2009 (Table 10 in Appendix).

Last, as small migration flows are likely to be less precisely estimated in the EMIF scheme, this may result in artificial variation of our aggregate measures of migration for those states with little emigration to the US. We test the robustness of our main results by excluding observations corresponding to the bottom 5% of the distribution of migration flows from our regression sample. The results are shown in Table 11 in Appendix and are very close to those presented in our main tables.

[35] Since the definition of GDP aggregates by the Mexican Statistical Institute (INEGI) has changed in 2003, we interact our GDP variable with a dummy equal to one for years 2003 to 2012

5.4 Distributional effects

In this section, we provide an alternative exploration of the impact of the different pro-poor reforms of PROCAMPO that were implemented in the 2000s. Instead of investigating the impact of total amounts paid to small plots around the 5 hectare threshold, we focus on changes in the entire distribution of PROCAMPO. Indeed, the different reforms of PROCAMPO, by increasing in particular the amounts received by the smallest producers, have contributed to reduce inequalities. Table 2 presents the estimation results of equation 1 in which the amount of PROCAMPO is replaced by two different measures of inequality in its distribution. The first one is the share of PROCAMPO transfers allocated to non irrigated plots in the *ejido* sector. The *ejido* sector concentrates many vulnerable producers, and non irrigated plots are likely to suffer more from climate shocks. Indeed, irrigation is expected to reduce the impact of climate shocks on migration (Benonnier et al., 2018). The second one is the Gini coefficient for the transfers received by producers. As explained in section 4, to avoid endogeneity issues, both measures are based on predicted PROCAMPO amounts : they combine the distribution of plots in 1999 with the yearly evolutions of the PROCAMPO benefits they were theoretically entitled to in the subsequent years. To facilitate the reading of the table, both measures are constructed such that an increase in the variable represents a more redistributive program.

An increase in the share of PROCAMPO received by producers in the non-irrigated *ejido* sector is associated with a lower total migration response to rainfall deviations during the dry season (column (1)), driven by undocumented flows (column (3)), which is consistent with our main findings presented in Table 1. Columns (3) and (5) suggest that an increase in the share of PROCAMPO amounts paid to the non-irrigated *ejido* sector is associated with an increase in either documented migration after heavy rainfall (col. (3)), or undocumented migration after a hurricane (col. (5)). However, variations in the share of PROCAMPO amounts paid to the non-irrigated *ejido* sector are driven by the initial distribution of such type of land in the different states, which could also be related to subsequent migration patterns. Unlike our preferred measure of PROCAMPO which exploits variations around the 5 hectare threshold, this measure is likely to capture the impact of characteristics of states that could be related to migration trends. We are thus careful not to overinterpret these results.

Inequality in the distribution of PROCAMPO measured by the Gini has no significant effect on migration in response to any shock except temperature deviations during the dry season (columns (2) and (6)). Note that this effect could be driven either by positive or negative variation in temperatures, as the effect of temperature on migration is not driven by positive rather than negative variations (see Table 12). But interestingly, a reduction of inequality has a mitigating role. Negative (resp. positive) temperature shocks during the dry season increase (resp. decrease) migration flows, but less so when inequality is lower.

Table 2: Impact of public policies : share of non irrigated PROCAMPO

Cube root dependent variable	Total male flows		Documented male flows		Undocumented male flows	
	(1)	(2)	(3)	(4)	(5)	(6)
Cube root amt Fonden $_{t-1}$	0.045***	0.041***	0.046**	0.043**	0.017	0.008
	(0.01)	(0.02)	(0.02)	(0.02)	(0.01)	(0.01)
Hurricane in $_{t-1}$	0.052	0.241	0.337	0.937	-0.446*	-0.445
	(0.30)	(0.69)	(0.30)	(0.61)	(0.26)	(0.59)
Hurricane max intensity $_{t-1}$	-0.099**	-0.104**	-0.059	-0.055	-0.049	-0.048
	(0.04)	(0.05)	(0.06)	(0.06)	(0.04)	(0.04)
Nb months rain >90th ptile $_{t-1}$	-0.040	-0.173	-0.163	-0.337	0.089	0.137
	(0.08)	(0.21)	(0.10)	(0.23)	(0.09)	(0.20)
Rain deviation rainy s. $_{t-1}$	-0.038	0.157	0.030	0.051	0.046	0.221
	(0.14)	(0.33)	(0.13)	(0.37)	(0.14)	(0.29)
Rain deviation dry s. $_{t-1}$	-0.435***	-0.327	-0.104	-0.072	-0.449**	-0.459
	(0.14)	(0.27)	(0.15)	(0.30)	(0.21)	(0.28)
Temp deviation rainy s. $_{t-1}$	-0.020	0.307	-0.045	-0.016	0.068	0.379
	(0.17)	(0.39)	(0.20)	(0.47)	(0.12)	(0.31)
Temp deviation dry s. $_{t-1}$	-0.368*	-0.932**	-0.197	-0.655	-0.374**	-0.743**
	(0.22)	(0.42)	(0.25)	(0.45)	(0.16)	(0.34)
Predicted share of PROCAMPO for non irrigated *ejidos* $_{t-1}$	-16.943***		-24.543***		-13.928**	
	(6.40)		(8.03)		(6.64)	
Hurricane in $_{t-1}$ XPROC. sh no irrig -*Ej.* $_{t-1}$	0.264		-0.256		0.665**	
	(0.36)		(0.35)		(0.28)	
Months rain > 90th ptile $_{t-1}$ Xsh PROC. no irrig. *Ej* $_{t-1}$	0.034		0.229**		-0.129	
	(0.09)		(0.12)		(0.10)	
Rain deviation rainy s. $_{t-1}$ XPROC. sh no irrig -*Ej.* $_{t-1}$	0.020		-0.147		-0.071	
	(0.16)		(0.15)		(0.16)	
Rain deviation dry s. $_{t-1}$ XPROC. sh no irrig -*Ej.* $_{t-1}$	0.457***		0.159		0.466**	
	(0.16)		(0.18)		(0.24)	
Temp deviation rainy s. $_{t-1}$ XPROC. sh no irrig -*Ej.* $_{t-1}$	0.189		0.193		-0.068	
	(0.19)		(0.23)		(0.15)	
Temp deviation dry s. $_{t-1}$ XPROC. sh no irrig -*Ej.* $_{t-1}$	0.337		0.081		0.444**	
	(0.24)		(0.27)		(0.19)	
(1-PROCAMPO gini) $_{t-1}$		0.046		-0.808		-7.186
		(5.41)		(7.19)		(4.55)
Hurricane in $_{t-1}$ X (1-PROCAMPO gini) $_{t-1}$		0.121		-1.425		0.989
		(1.27)		(1.13)		(1.06)
Nb months rain >90th ptile $_{t-1}$ X (1-PROCAMPO gini) $_{t-1}$		0.266		0.633		-0.286
		(0.39)		(0.41)		(0.36)
Rain deviation rainy s. $_{t-1}$ X (1-PROCAMPO gini) $_{t-1}$		-0.341		-0.275		-0.421
		(0.56)		(0.64)		(0.52)
Rain deviation dry s. $_{t-1}$ X (1-PROCAMPO gini) $_{t-1}$		0.457		0.125		0.703
		(0.46)		(0.52)		(0.48)
Temp deviation rainy s. $_{t-1}$ X (1-PROCAMPO gini) $_{t-1}$		-0.335		0.200		-0.618
		(0.65)		(0.78)		(0.56)
Temp deviation dry s. $_{t-1}$ X (1-PROCAMPO gini) $_{t-1}$		1.522**		0.941		1.288**
		(0.72)		(0.76)		(0.58)
N	384	384	384	384	384	384

Standard errors corrected for autocorrelation and spatial correlation in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

6 Conclusion

Using unique panel data documenting migration flows from Mexican states to the US over the 1995-2009 period, we explore the impact of rainfall and temperature shocks on migration rates to the US and the mitigating role of two public programs, an agricultural cash-transfer program (PROCAMPO) and a disaster fund (Fonden). We exploit the panel dimension of our data to control for origin and year fixed effects and account for spatial and serial correlation. In addition, our state-level data being constructed from an individual survey, we are able to separately analyze documented and undocumented flows.

We find evidence that public policies mitigate the impact of weather shocks on migration. Our results highlight the importance of a disaster fund, Fonden, as well as of reforms reducing inequalities in the agricultural sector, in lowering the migration response to weather shocks, with a seemingly larger mitigating effect on undocumented migration. An increase in amounts transferred under Fonden limits the migration response to hurricanes, heavy rainfall, and abnormally low rainfall during the dry season. The effect of Fonden is particularly important on undocumented migrant flows. In addition, an increase in the redistributive attributes of PROCAMPO - more specifically, a larger amount paid to small plots, as well as a larger share received by farmers in the *ejido* sector for non-irrigated land - tends to reduce undocumented migration after some weather shocks, and particularly rain deviations during the dry season.

As weather variability is believed to increase as a consequence of climate change, recurring droughts episodes or more frequent hurricanes are expected to contribute to increase migration flows from Mexican states. Consistent with del Valle et al. (2020), this paper highlights the impact of well targeted public policies such as disaster funds on climate-induced migration. This paper also suggests that reducing income inequality in the agricultural sector might lower climate-induced migration. Although apparently disconnected from weather-related shocks, redistributive PROCAMPO reforms appear to have somewhat reduced the impact of droughts on migration.

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Appendix A: Additional tables and figures

Table 3: Contribution of Mexicans states to total Mexico-US migration flows (2004-2009 - top ten states of origin) : comparison between data from EMIF and ENADID

EMIF		**ENADID**	
Guanajuato	13.2	Michoacán	10.3
Chiapas	10.5	Veracruz	8.6
Michoacan	8.8	Guanajuato	8.3
Jalisco	6.4	Jalisco	8.0
Veracruz	6.0	Puebla[1]	5.1
Oaxaca	5.8	Oaxaca	5.0
Sonora	4.8	Hidalgo[2]	4.8
Mexico	4.7	Guerrero	4.8
Sinaloa	4.0	México	4.2
Guerrero	3.7	Chiapas	4.1

Sources : EMIF 2004-2009 (authors' calculations), INEGI, ENADID 2009

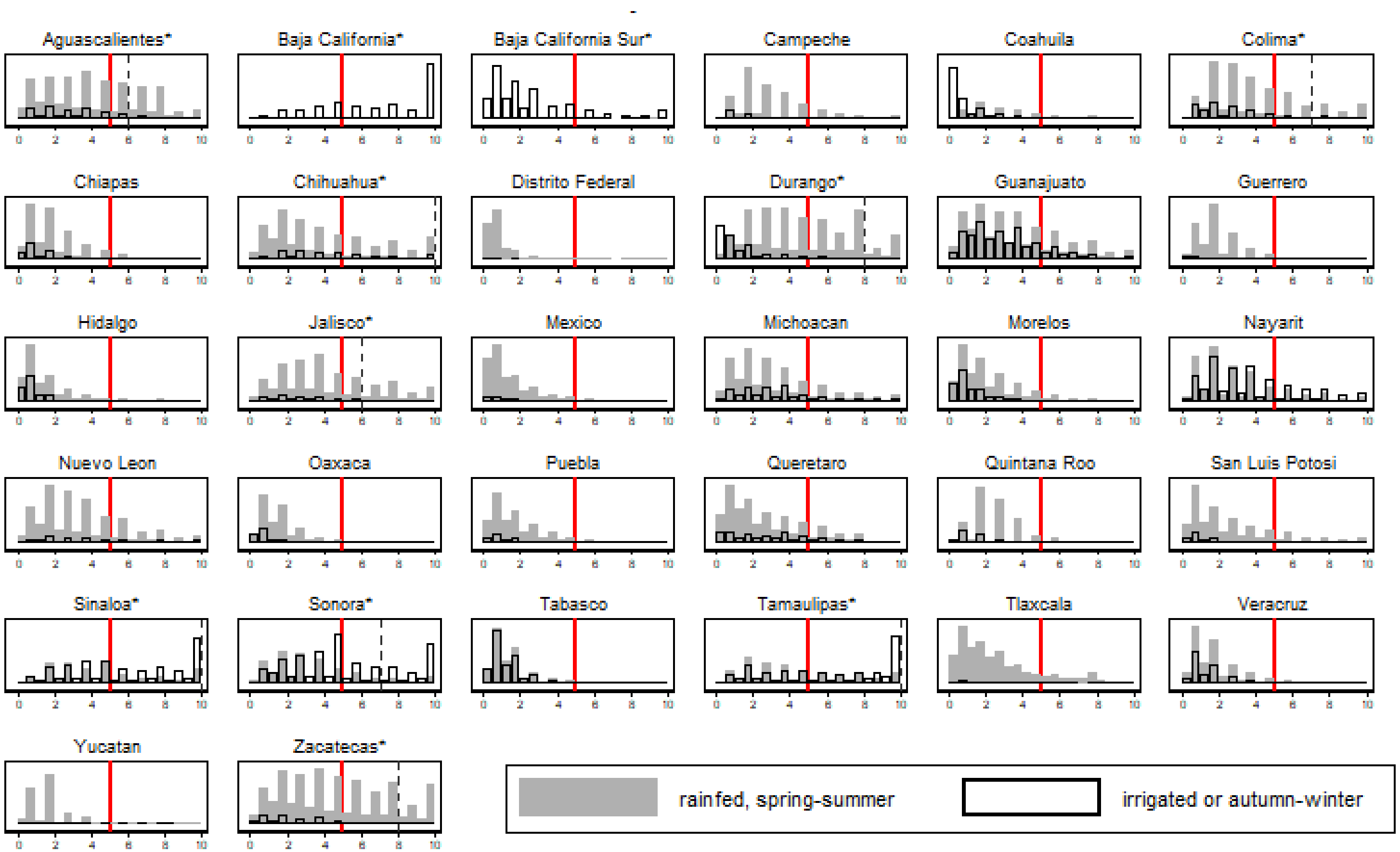
[1] Based on EMIF data, Puebla is ranked 11th with 3.6% of total flows

[2] Based on EMIF data, Hidalgo is ranked 12th with 3.4% of total flows

Table 4: Summary statistics

Variable	**Mean**	**Std. Dev.**
Cube root male migration rate	3.298	1.143
Cube root male documented migration rate	2.013	1.088
Cube root male undocumented migration rate	2.824	1.119
Ln male migration rate	3.267	2.035
Ln male documented migration rat	1.294	2.868
Ln undocumented male migration rate	2.566	2.967
Log pred. PROCAMPO $<$ 10ha	18.859	1.352
Cube root amt Fonden $_{t-1}$	2.006	2.454
Hurricane in $_{t-1}$	0.167	0.373
Hurricane max intensity $_{t-1}$	0.552	1.225
Nb months rain $>$ 90th ptile $_{t-1}$	1.576	1.224
Rain deviation rainy season $_{t-1}$	0.449	1.064
Rain deviation dry season $_{t-1}$	0.156	1.015
Temp deviation rainy season $_{t-1}$	0.498	0.908
Temp deviation dry season $_{t-1}$	0.268	0.927
N	384	

Figure 5: Distribution of plots of less than 10 hectares in 1999



The thick red line materializes the 5 hectare threshold. Rainfed plots in the spring-summer cycle of less than 5 hectares benefited from the highest PROCAMPO per hectare payments following the 2003 and the 2009 reforms. ⋆ In 11 states, rainfed plots in the spring-summer cycle above 5 hectares and below a state specific threshold were also eligible to an improved per hectare payment from 2003 to 2009. This specific threshold (if below 10 hectares) is represented on the graph by a dashed line.

Figure 6: Rainfall during the rainy season - Z-score density by state (2000-2010)

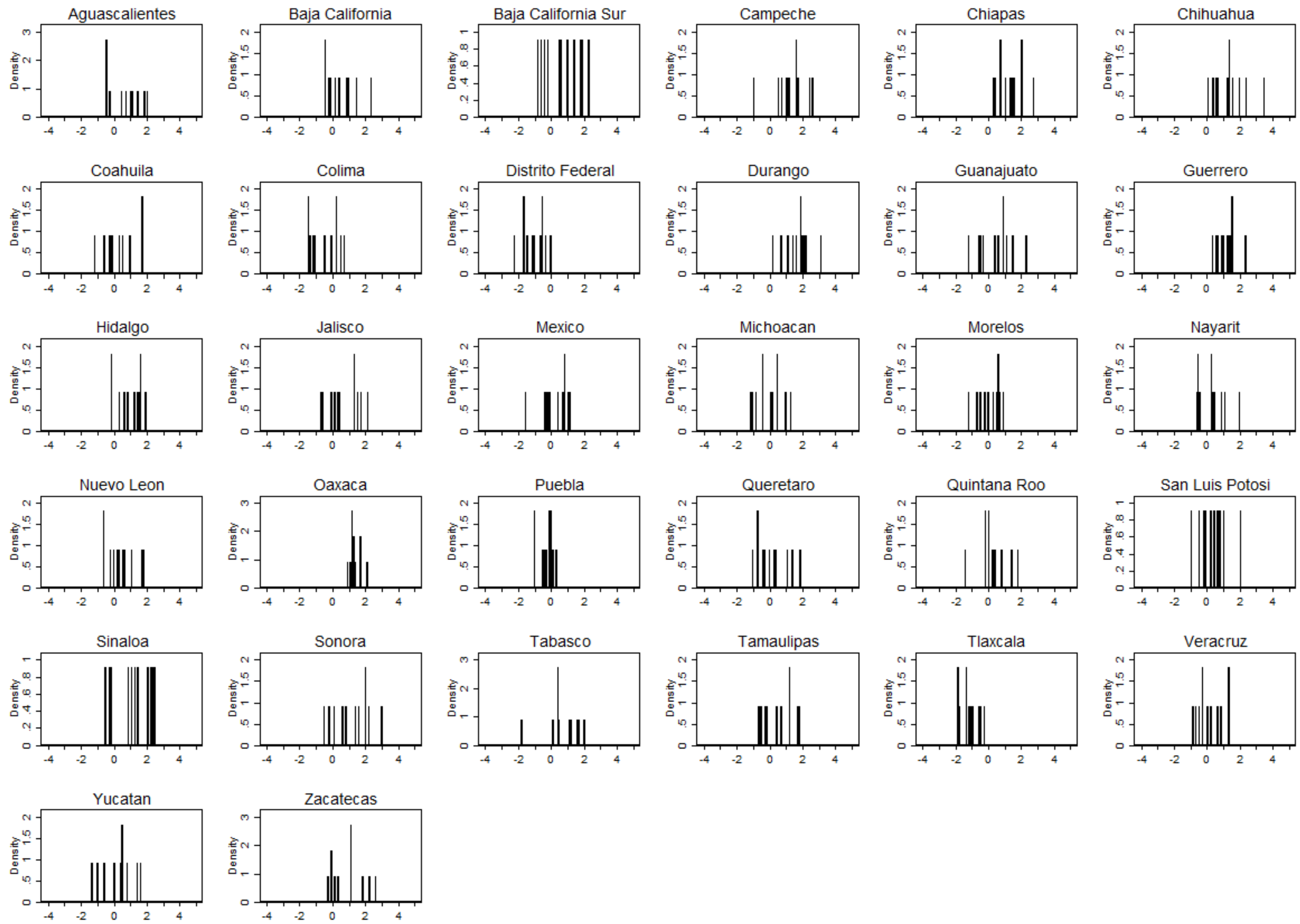


Figure 7: Rainfall during the dry season - Z-score density by state (2000-2010)

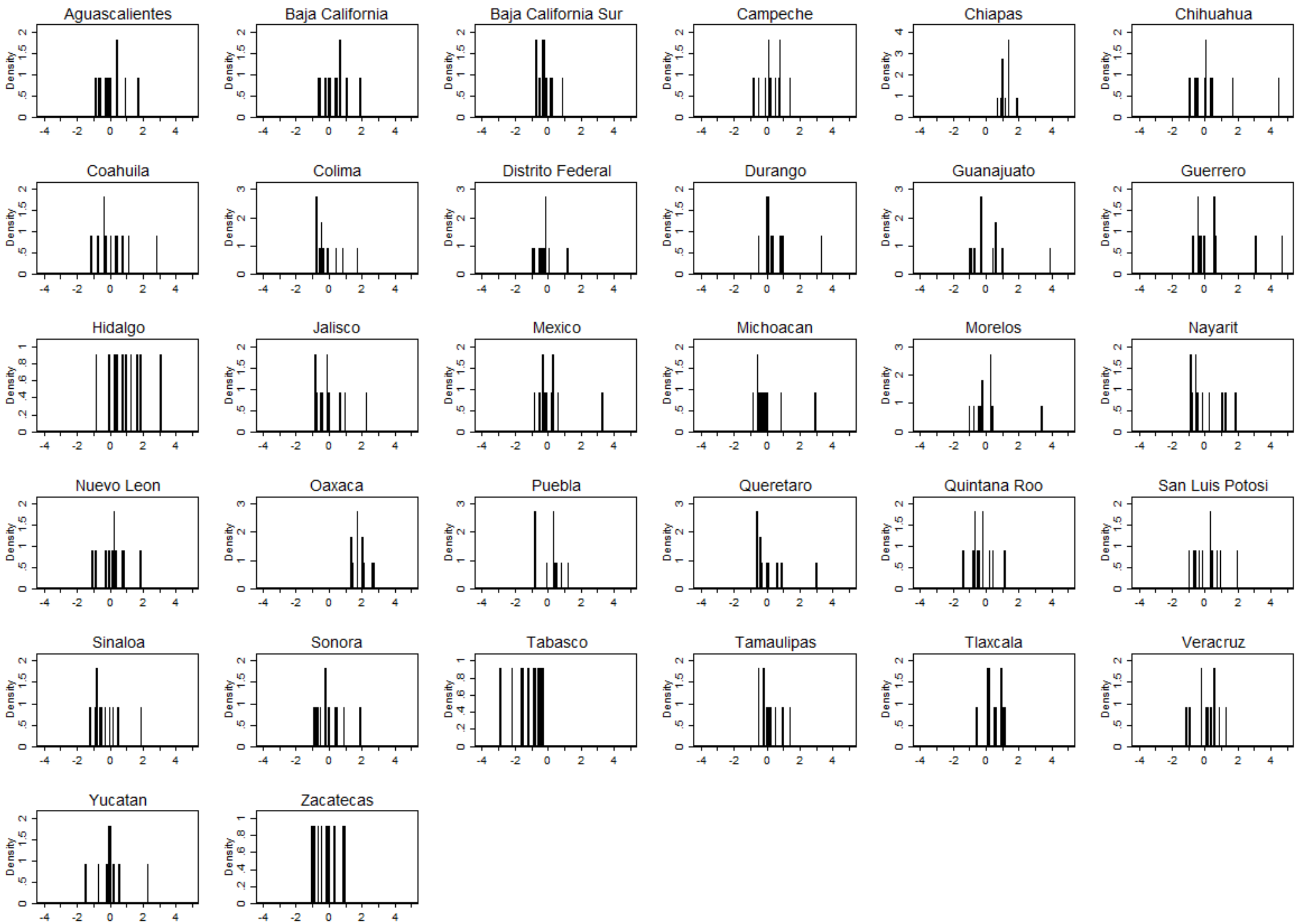


Figure 8: Temperature during the rainy season - Z-score density by state (2000-2010)

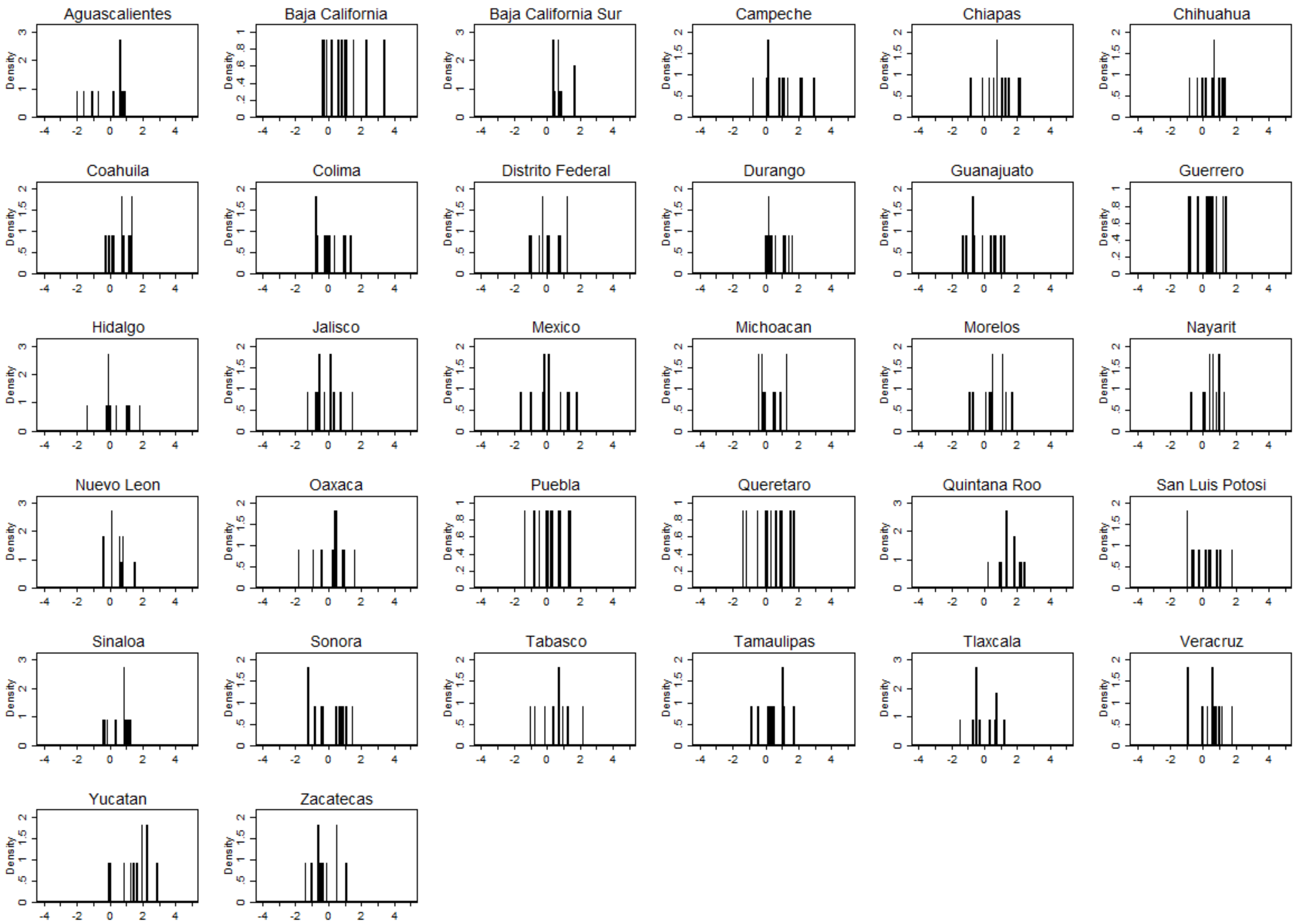


Figure 9: Temperature during the dry season - Z-score density by state (2000-2010)

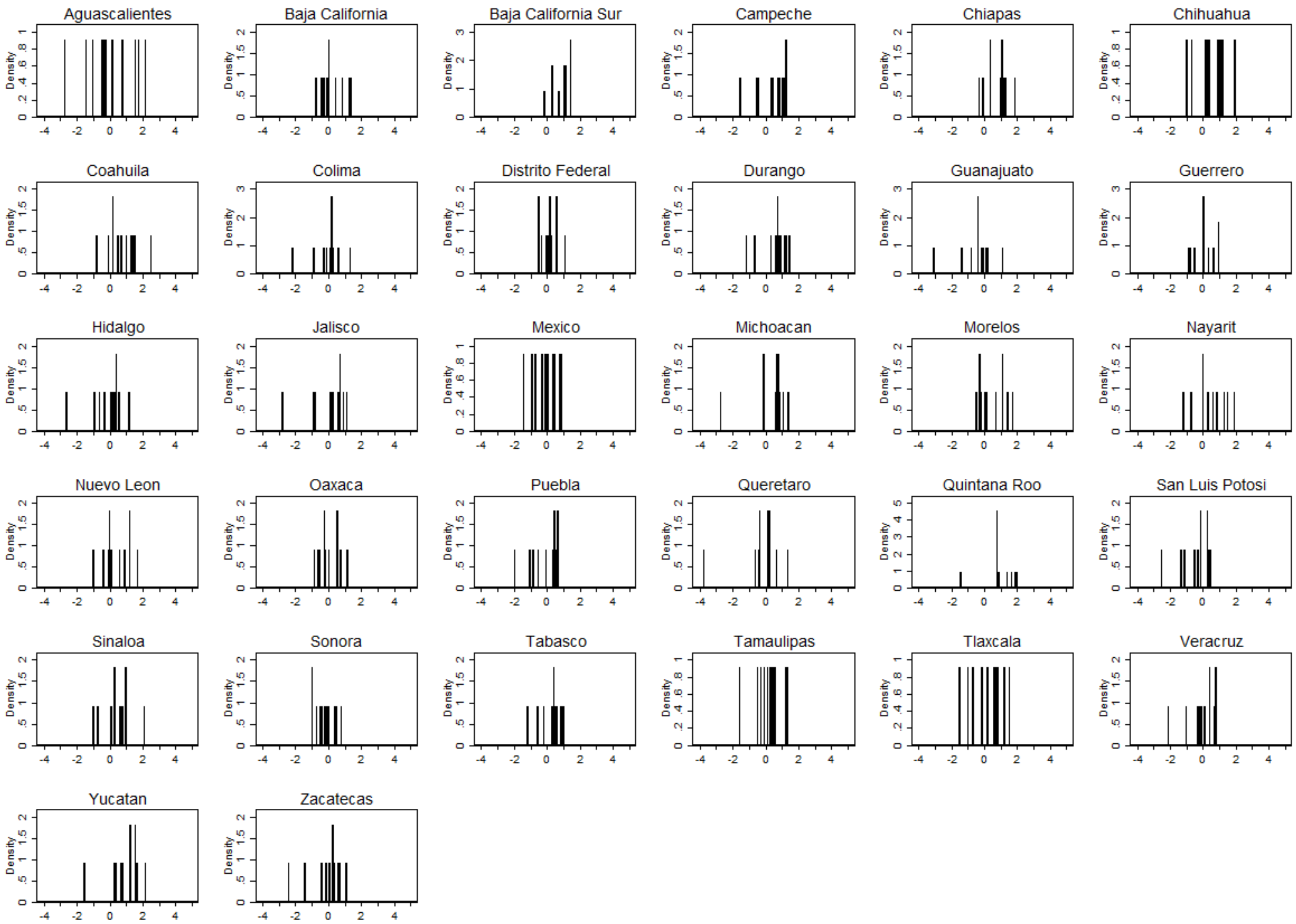


Table 5: Fonden and past migration

Cube root dependent variable	Cube root Fonden per capita (1)	(2)	(3)
Cube root male migration rate $_{t-1}$	-0.116		
	(0.20)		
Cube root male documented migration rate $_{t-1}$		0.223	
		(0.19)	
Cube root male undocumented migration rate $_{t-1}$			-0.317
			(0.20)
Hurricane	-2.116***	-2.093***	-2.094***
	(0.63)	(0.65)	(0.62)
Hurricane max intensity $_t$	1.142***	1.128***	1.136***
	(0.16)	(0.17)	(0.16)
Nb months rain >90th ptile $_t$	0.056	0.037	0.052
	(0.13)	(0.13)	(0.13)
Rain anomalies during rainy season (z-score)$_t$	0.393**	0.415**	0.403**
	(0.20)	(0.20)	(0.19)
Rain anomalies during dry season (z-score)$_t$	0.000	0.019	0.008
	(0.15)	(0.15)	(0.15)
temp deviations in rainy season by state$_t$	-0.116	-0.108	-0.111
	(0.23)	(0.23)	(0.23)
temp deviations in dry season by state $_t$	0.452**	0.455**	0.453**
	(0.21)	(0.21)	(0.21)
Hurricane in $_{t-1}$	-1.080	-1.057	-1.088
	(0.79)	(0.81)	(0.77)
Nb months rain >90th ptile $_{t-1}$	0.082	0.069	0.077
	(0.13)	(0.13)	(0.13)
Hurricane max intensity $_{t-1}$	0.799***	0.794***	0.793***
	(0.24)	(0.25)	(0.24)
Rain deviation rainy s. $_{t-1}$	-0.104	-0.098	-0.105
	(0.19)	(0.18)	(0.19)
Rain deviation dry s. $_{t-1}$	-0.303**	-0.283*	-0.303*
	(0.15)	(0.15)	(0.16)
Temp deviation rainy s. $_{t-1}$	0.115	0.072	0.107
	(0.21)	(0.22)	(0.22)
Temp deviation dry s. $_{t-1}$	-0.018	-0.016	-0.011
	(0.24)	(0.24)	(0.24)
N	384	384	384

Standard errors corrected for autocorrelation and spatial correlation in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$
* Controls include hurricanes, hurricanes maximum intensity, number of heavy rainfalls,
* rainfall and temperature in dry and rainy season,in t and $t-1$.

Table 6: Climatic factors and Mexico-US migration flows : impact of public policies, 1999-2011

Cube root dependent variable	Total male flows (1)	Documented male flows (2)	Undocumented male flows (3)
Log PROCAMPO around the threshold (+- 1ha) $_{t-1}$	-0.035	0.213	-0.215
	(0.18)	(0.18)	(0.16)
Cube root amt Fonden $_{t-1}$	0.048**	0.067**	-0.000
	(0.02)	(0.03)	(0.02)
Hurricane in $_{t-1}$	0.327**	0.139	0.133
	(0.16)	(0.21)	(0.12)
Hurricane max intensity $_{t-1}$	-0.069	-0.074	0.001
	(0.05)	(0.06)	(0.04)
Nb months rain >90th ptile $_{t-1}$	0.012	0.077*	-0.012
	(0.05)	(0.05)	(0.05)
Rain deviation rainy s. $_{t-1}$	-0.064	-0.134**	-0.044
	(0.06)	(0.06)	(0.06)
Rain deviation dry s. $_{t-1}$	-0.137***	-0.031	-0.117**
	(0.04)	(0.05)	(0.05)
Temp deviation rainy s. $_{t-1}$	0.113	0.078	0.023
	(0.07)	(0.07)	(0.05)
Temp deviation dry s. $_{t-1}$	-0.094	-0.119	-0.011
	(0.07)	(0.08)	(0.05)
Hurricane in $_{t-1}$ XCube root Fonden $_{t-1}$	-0.043	0.014	-0.052**
	(0.03)	(0.04)	(0.03)
Nb months rain >90th ptile $_{t-1}$ XCube root Fonden $_{t-1}$	-0.015	-0.028**	-0.002
	(0.01)	(0.01)	(0.01)
Rain deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$	0.018	0.020*	0.015
	(0.01)	(0.01)	(0.01)
Rain deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$	0.031***	0.013	0.028***
	(0.01)	(0.01)	(0.01)
Temp deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$	0.013	0.019	0.008
	(0.01)	(0.02)	(0.01)
Temp deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$	0.014	0.001	0.010
	(0.01)	(0.01)	(0.01)
N	384	384	384

Standard errors corrected for autocorrelation and spatial correlation in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 7: Climatic factors and Mexico-US migration flows : impact of public policies, 2001-2011. Inverse hyperbolic sine dependent variable.

Inv. hyperbol. sine dependent var.	Total male flows		Documented male flows		Undocumented male flows	
	(1)	(2)	(3)	(4)	(5)	(6)
Log PROCAMPO around the threshold (+/- 1ha) $_{t-1}$	-0.036	0.025	0.156	0.212	-0.221	-0.168
	(0.20)	(0.20)	(0.22)	(0.22)	(0.21)	(0.22)
Cube root amt Fonden $_{t-1}$	0.038***	0.054**	0.060**	0.080**	0.002	0.005
	(0.01)	(0.02)	(0.02)	(0.04)	(0.01)	(0.03)
Hurricane in $_{t-1}$	0.985	0.245	-1.479	0.113	-0.381	0.052
	(1.37)	(0.18)	(2.16)	(0.24)	(1.41)	(0.15)
Hurricane max intensity $_{t-1}$	-0.046	-0.035	-0.050	-0.075	0.018	0.048
	(0.05)	(0.06)	(0.08)	(0.08)	(0.05)	(0.05)
Nb months rain >90th ptile $_{t-1}$	-0.986**	0.033	-0.704	0.114**	-0.543	0.006
	(0.48)	(0.05)	(0.70)	(0.05)	(0.56)	(0.05)
Rain deviation rainy s. $_{t-1}$	-0.721	-0.085	0.300	-0.218***	0.019	-0.056
	(0.50)	(0.07)	(0.72)	(0.07)	(0.62)	(0.07)
Rain deviation dry s. $_{t-1}$	-0.234	-0.105**	0.748	-0.009	-0.620	-0.094*
	(0.58)	(0.04)	(0.80)	(0.06)	(0.74)	(0.05)
Temp deviation rainy s. $_{t-1}$	-0.766	0.078	0.488	0.036	-0.202	0.001
	(0.55)	(0.06)	(0.71)	(0.07)	(0.63)	(0.06)
Temp deviation dry s. $_{t-1}$	-0.438	-0.074	0.662	-0.135	-0.676	0.018
	(0.65)	(0.06)	(0.89)	(0.09)	(0.75)	(0.06)
Hurricane in $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	-0.044		0.091		0.020	
	(0.08)		(0.12)		(0.08)	
Nb months rain >90th ptile $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.054**		0.041		0.030	
	(0.03)		(0.04)		(0.03)	
Rain deviation rainy s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.038		-0.026		-0.002	
	(0.03)		(0.04)		(0.03)	
Rain deviation dry s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.012		-0.041		0.035	
	(0.03)		(0.04)		(0.04)	
Temp deviation rainy s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.050		-0.023		0.013	
	(0.03)		(0.04)		(0.04)	
Temp deviation dry s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.022		-0.046		0.040	
	(0.04)		(0.05)		(0.04)	
Hurricane in $_{t-1}$ XCube root Fonden $_{t-1}$		-0.036		0.023		-0.060**
		(0.04)		(0.05)		(0.03)
Nb months rain >90th ptile $_{t-1}$ XCube root Fonden $_{t-1}$		-0.024**		-0.038**		-0.011
		(0.01)		(0.02)		(0.01)
Rain deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.019		0.028*		0.020
		(0.01)		(0.02)		(0.02)
Rain deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.033***		0.009		0.032***
		(0.01)		(0.01)		(0.01)
Temp deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.020		0.031		0.014
		(0.02)		(0.03)		(0.01)
Temp deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.010		-0.006		0.006
		(0.01)		(0.01)		(0.01)
N	384	384	384	384	384	384

Standard errors corrected for autocorrelation and spatial correlation in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 8: Climatic factors and Mexico-US migration flows : impact of public policies, Fonden in log - 2001-2011

Cube root dependent variables	Total male flows (1)	Documented male flows (2)	Undocumented male flows (3)
Log PROCAMPO around the threshold (+/- 1ha) $_{t-1}$	-0.033	0.211	-0.218
	(0.18)	(0.18)	(0.16)
Log amount Fonden $_{t-1}$	0.011	0.019**	-0.001
	(0.01)	(0.01)	(0.01)
Hurricane in $_{t-1}$	0.212	0.139	0.005
	(0.14)	(0.16)	(0.11)
Hurricane max intensity $_{t-1}$	-0.068	-0.060	-0.002
	(0.04)	(0.06)	(0.04)
Nb months rain >90th ptile $_{t-1}$	-0.035	-0.002	-0.022
	(0.03)	(0.04)	(0.03)
Rain deviation rainy s. $_{t-1}$	0.006	-0.045	-0.003
	(0.05)	(0.05)	(0.04)
Rain deviation dry s. $_{t-1}$	-0.050	0.010	-0.041
	(0.03)	(0.04)	(0.03)
Temp deviation rainy s. $_{t-1}$	0.164**	0.134*	0.050
	(0.08)	(0.08)	(0.05)
Temp deviation dry s. $_{t-1}$	-0.039	-0.093	0.020
	(0.06)	(0.07)	(0.05)
Hurricane in $_{t-1}$ X Log amount Fonden $_{t-1}$	-0.013	0.009	-0.020
	(0.01)	(0.01)	(0.01)
Nb months rain >90th ptile $_{t-1}$ X Log amount Fonden $_{t-1}$	-0.008*	-0.014***	-0.001
	(0.00)	(0.00)	(0.00)
Rain deviation rainy s. $_{t-1}$ X Log amount Fonden $_{t-1}$	0.012***	0.017***	0.004
	(0.00)	(0.01)	(0.01)
Rain deviation dry s. $_{t-1}$ X Log amount Fonden $_{t-1}$	0.014***	0.008*	0.013***
	(0.00)	(0.00)	(0.00)
Temp deviation rainy s. $_{t-1}$ X Log amount Fonden $_{t-1}$	0.009**	0.006	0.005
	(0.00)	(0.01)	(0.00)
Temp deviation dry s. $_{t-1}$ X Log amount Fonden $_{t-1}$	0.006	0.006	0.003
	(0.01)	(0.01)	(0.00)
N	384	384	384

Standard errors corrected for autocorrelation and spatial correlation in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 9: Climatic factors and Mexico-US migration flows, 2001-2011. With economic controls

Cube root dependent variable	Total male flows (1)	(2)	Documented male flows (3)	(4)	Undocumented male flows (5)	(6)
Log PROCAMPO around the threshold (+/- 1ha) $_{t-1}$	-0.047	0.021	0.182	0.244	-0.212	-0.183
	(0.18)	(0.17)	(0.19)	(0.18)	(0.15)	(0.15)
Log amount Fonden $_{t-1}$	0.009**	0.005	0.012*	0.011*	0.000	-0.003
	(0.00)	(0.00)	(0.01)	(0.01)	(0.00)	(0.01)
Hurricane in $_{t-1}$	0.544	0.341**	-1.563	0.103	0.272	0.180
	(1.28)	(0.16)	(1.84)	(0.19)	(1.15)	(0.12)
Hurricane max intensity $_{t-1}$	-0.052	-0.070	-0.018	-0.065	-0.016	-0.008
	(0.04)	(0.04)	(0.05)	(0.06)	(0.04)	(0.04)
Nb months rain >90th ptile $_{t-1}$	-0.625	-0.013	-0.651	0.052	-0.082	-0.022
	(0.43)	(0.05)	(0.49)	(0.04)	(0.45)	(0.04)
Ln GDP per capita $_{t-1}$	0.659**	0.753***	0.589**	0.470*	0.152	0.251
	(0.27)	(0.25)	(0.26)	(0.25)	(0.18)	(0.18)
Ln GDP per capita $_{t-1}$ X post 2003	-0.367**	-0.358**	-0.507***	-0.374***	-0.000	0.012
	(0.15)	(0.15)	(0.15)	(0.14)	(0.15)	(0.15)
Unemployment rate $_{t-1}$	0.033	0.035	-0.026	-0.018	0.069**	0.065*
	(0.04)	(0.04)	(0.04)	(0.04)	(0.03)	(0.03)
Ln share of homicides $_{t-1}$	-0.086	-0.086	-0.017	-0.042	-0.114	-0.101
	(0.09)	(0.09)	(0.09)	(0.09)	(0.07)	(0.07)
Rain deviation rainy s. $_{t-1}$	-0.577	-0.058	0.463	-0.135**	-0.427	-0.036
	(0.48)	(0.06)	(0.62)	(0.06)	(0.51)	(0.06)
Rain deviation dry s. $_{t-1}$	-0.167	-0.115**	0.867	-0.015	-0.806	-0.108**
	(0.48)	(0.05)	(0.56)	(0.05)	(0.59)	(0.05)
Temp deviation rainy s. $_{t-1}$	0.005	0.050	1.040	0.026	-0.019	0.003
	(0.57)	(0.06)	(0.65)	(0.07)	(0.61)	(0.05)
Temp deviation dry s. $_{t-1}$	-0.484	-0.074	0.471	-0.113	-0.919	0.003
	(0.57)	(0.06)	(0.65)	(0.08)	(0.61)	(0.05)
Hurricane in $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	-0.018		0.093		-0.012	
	(0.07)		(0.10)		(0.06)	
Nb months rain >90th ptile $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.034		0.038		0.003	
	(0.02)		(0.03)		(0.02)	
Rain deviation rainy s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.032		-0.032		0.025	
	(0.03)		(0.03)		(0.03)	
Rain deviation dry s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.008		-0.048		0.044	
	(0.03)		(0.03)		(0.03)	
Temp deviation rainy s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.005		-0.056		0.003	
	(0.03)		(0.04)		(0.04)	
Temp deviation dry s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.025		-0.033		0.053	
	(0.03)		(0.04)		(0.03)	
Hurricane in $_{t-1}$ XCube root Fonden $_{t-1}$		-0.034		0.028		-0.054**
		(0.03)		(0.04)		(0.03)
Nb months rain >90th ptile $_{t-1}$ XCube root Fonden $_{t-1}$		-0.008		-0.018*		-0.002
		(0.01)		(0.01)		(0.01)
Rain deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.018		0.018		0.017
		(0.01)		(0.01)		(0.01)
Rain deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.031***		0.010		0.028***
		(0.01)		(0.01)		(0.01)
Temp deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.024		0.027		0.014
		(0.01)		(0.02)		(0.01)
Temp deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.016		0.004		0.010
		(0.01)		(0.01)		(0.01)
N	384	384	384	384	384	384

Standard errors corrected for autocorrelation and spatial correlation in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 10: Climatic factors and Mexico-US migration flows : impact of public policies, 2001-2011. Without 2010 (2009 being an exceptional drought)

Cube root dependent variable	Total male flows		Documented male flows		Undocumented male flows	
	(1)	(2)	(3)	(4)	(5)	(6)
Log PROCAMPO around the threshold (+/- 1ha) $_{t-1}$	-0.136	-0.092	0.097	0.145	-0.283*	-0.258
	(0.19)	(0.18)	(0.18)	(0.17)	(0.16)	(0.17)
Cube root amt Fonden $_{t-1}$	0.047***	0.051**	0.054***	0.063**	0.009	0.010
	(0.01)	(0.02)	(0.02)	(0.03)	(0.01)	(0.03)
Hurricane in $_{t-1}$	0.577	0.379**	-1.170	0.186	-0.112	0.162
	(1.20)	(0.17)	(1.69)	(0.21)	(1.19)	(0.14)
Hurricane max intensity $_{t-1}$	-0.083*	-0.070	-0.057	-0.079	-0.021	0.005
	(0.05)	(0.05)	(0.06)	(0.06)	(0.04)	(0.04)
Nb months rain >90th ptile $_{t-1}$	-0.584	-0.003	-0.454	0.060	-0.102	-0.015
	(0.52)	(0.05)	(0.56)	(0.05)	(0.53)	(0.05)
Rain deviation rainy s. $_{t-1}$	-1.043**	-0.036	-0.029	-0.100*	-0.495	-0.025
	(0.48)	(0.06)	(0.55)	(0.06)	(0.53)	(0.06)
Rain deviation dry s. $_{t-1}$	-0.503	-0.140***	0.495	-0.037	-0.979	-0.122**
	(0.51)	(0.05)	(0.60)	(0.05)	(0.68)	(0.05)
Temp deviation rainy s. $_{t-1}$	-0.440	0.104	0.741	0.068	-0.216	0.024
	(0.56)	(0.07)	(0.50)	(0.07)	(0.66)	(0.06)
Temp deviation dry s. $_{t-1}$	-0.568	-0.095	0.462	-0.116	-0.939	-0.005
	(0.59)	(0.07)	(0.67)	(0.09)	(0.63)	(0.06)
Hurricane in $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	-0.017		0.075		0.010	
	(0.07)		(0.09)		(0.07)	
Nb months rain >90th ptile $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.031		0.026		0.004	
	(0.03)		(0.03)		(0.03)	
Rain deviation rainy s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.059**		-0.002		0.029	
	(0.03)		(0.03)		(0.03)	
Rain deviation dry s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.026		-0.028		0.054	
	(0.03)		(0.03)		(0.04)	
Temp deviation rainy s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.034		-0.036		0.015	
	(0.03)		(0.03)		(0.04)	
Temp deviation dry s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.029		-0.033		0.054	
	(0.03)		(0.04)		(0.04)	
Hurricane in $_{t-1}$ XCube root Fonden $_{t-1}$		-0.056		0.003		-0.062**
		(0.04)		(0.04)		(0.03)
Nb months rain >90th ptile $_{t-1}$ XCube root Fonden $_{t-1}$		-0.014		-0.026*		-0.005
		(0.01)		(0.01)		(0.01)
Rain deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.016		0.019		0.014
		(0.01)		(0.01)		(0.01)
Rain deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.033***		0.014		0.030***
		(0.01)		(0.01)		(0.01)
Temp deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.025		0.033		0.011
		(0.02)		(0.02)		(0.01)
Temp deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.015		0.003		0.009
		(0.01)		(0.01)		(0.01)
N	352	352	352	352	352	352

Standard errors corrected for autocorrelation and spatial correlation in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Table 11: Climatic factors and Mexico-US migration flows : impact of public policies. Without bottom 5 percents

Cube root dependent variable	Total male flows		Documented male flows		Undocumented male flows	
	(1)	(2)	(3)	(4)	(5)	(6)
Log PROCAMPO around the threshold (+/- 1ha) $_{t-1}$	-0.008	-0.025	0.171	0.213	-0.238	-0.262
	(0.24)	(0.26)	(0.18)	(0.18)	(0.17)	(0.19)
Cube root amt Fonden $_{t-1}$	0.039***	0.033	0.050***	0.067**	0.002	-0.005
	(0.01)	(0.02)	(0.02)	(0.03)	(0.01)	(0.02)
Hurricane in $_{t-1}$	0.526	0.291*	-1.217	0.139	-0.550	0.129
	(1.12)	(0.16)	(1.64)	(0.21)	(1.05)	(0.11)
Hurricane max intensity $_{t-1}$	-0.074*	-0.065	-0.054	-0.074	-0.041	-0.006
	(0.05)	(0.04)	(0.06)	(0.06)	(0.04)	(0.04)
Nb months rain >90th ptile $_{t-1}$	-0.262	0.010	-0.556	0.077*	0.266	0.007
	(0.53)	(0.05)	(0.48)	(0.05)	(0.43)	(0.04)
Rain deviation rainy s. $_{t-1}$	-0.919*	-0.048	-0.017	-0.134**	-0.755*	-0.033
	(0.48)	(0.05)	(0.53)	(0.06)	(0.45)	(0.06)
Rain deviation dry s. $_{t-1}$	-0.702	-0.158***	0.615	-0.031	-0.853**	-0.132***
	(0.49)	(0.05)	(0.56)	(0.05)	(0.36)	(0.04)
Temp deviation rainy s. $_{t-1}$	-0.287	0.140*	0.528	0.078	-0.635	0.015
	(0.55)	(0.08)	(0.51)	(0.07)	(0.56)	(0.05)
Temp deviation dry s. $_{t-1}$	-0.564	-0.115	0.333	-0.119	-0.257	-0.014
	(0.69)	(0.08)	(0.64)	(0.08)	(0.52)	(0.06)
Hurricane in $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	-0.018		0.077		0.033	
	(0.06)		(0.09)		(0.06)	
Nb months rain >90th ptile $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.014		0.032		-0.015	
	(0.03)		(0.03)		(0.02)	
Rain deviation rainy s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.051*		-0.004		0.043*	
	(0.03)		(0.03)		(0.03)	
Rain deviation dry s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.035		-0.034		0.044**	
	(0.03)		(0.03)		(0.02)	
Temp deviation rainy s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.026		-0.024		0.038	
	(0.03)		(0.03)		(0.03)	
Temp deviation dry s. $_{t-1}$ X PROC. threshold +/- 1ha $_{t-1}$	0.027		-0.026		0.015	
	(0.04)		(0.03)		(0.03)	
Hurricane in $_{t-1}$ XCube root Fonden $_{t-1}$		-0.042		0.014		-0.067**
		(0.04)		(0.04)		(0.03)
Nb months rain >90th ptile $_{t-1}$ XCube root Fonden $_{t-1}$		-0.004		-0.028**		0.002
		(0.01)		(0.01)		(0.01)
Rain deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.013		0.020*		0.014
		(0.01)		(0.01)		(0.01)
Rain deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.028**		0.013		0.026**
		(0.01)		(0.01)		(0.01)
Temp deviation rainy s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.008		0.019		0.005
		(0.02)		(0.02)		(0.01)
Temp deviation dry s. $_{t-1}$ XCube root Fonden $_{t-1}$		0.018		0.001		0.011
		(0.02)		(0.01)		(0.01)
N	364	364	384	384	365	365

Standard errors corrected for autocorrelation and spatial correlation in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Appendix B: Impact of rainfall and temperatures

Table 12 shows the results of the estimation of the impact of climate shocks on migration, for total male flows (columns (1) to (3)), and then separately for documented male flows (columns (4) to (6)) and undocumented male flows (columns (7) to (9)). All specifications include state of origin and year fixed-effects and standards errors are corrected for serial and spatial correlation. The dependent variable is the cube root of the migration rate at the Mexican state level (per 10,000 inhabitants).

As suggested by estimation results reported in columns (1) to (3), hurricanes tend to increase migration. However the effect of hurricane intensity is not significant in most specifications.

We find a negative and significant coefficient on the precipitation z-score during the dry season and a positive and significant coefficient on the temperature z-score during the rainy season (column (1)).

Columns (3), (6) and (9) allow us to go further in the interpretation of our results by exploring separately the impact of positive and negative deviations from long term averages in rainfall and temperatures, that is, for each type of climate anomaly, the specifications disentangle positive and negative z-scores.

Documented migration increases when the rainfall are larger than average during the rainy season. Undocumented migration increases following negative rain shocks during the dry season. Indeed,

Since by construction all negative deviations variables take negative or zero values, the negative and significant coefficient on the negative rain deviations variable in column (6) suggests that precipitation shortage during the rainy season tends to increase documented migration. Similarly, droughts (negative rainfall deviations) during the dry season are found to increase undocumented migration (column (9)). Our findings are consistent with previous evidence of drought driven migration in the Mexican context (Pugatch and Yang, 2011; Chort, 2014; Chort and De La Rupelle, 2016; Nawrotzki et al., 2013).

As for temperatures, results in column (3) suggest that total flows are negatively affected by negative deviations during the rainy season.

Table 12: Climatic factors and Mexico-US migration flows - 1999-2011

Cube root dependent variable	Total male flows			Documented male flows			Undocumented male flows		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Hurricane in $_{t-1}$	0.253*	0.262*	0.233	0.048	0.100	0.043	0.122	0.113	0.109
	(0.15)	(0.14)	(0.15)	(0.15)	(0.14)	(0.16)	(0.13)	(0.13)	(0.13)
Hurricane max intensity $_{t-1}$	-0.063	-0.064	-0.062	-0.006	-0.029	-0.007	-0.045	-0.038	-0.043
	(0.05)	(0.04)	(0.05)	(0.05)	(0.05)	(0.05)	(0.04)	(0.04)	(0.04)
Nb months rain >90th ptile $_{t-1}$	-0.028	-0.060**	-0.023	0.020	-0.018	0.024	-0.026	-0.039	-0.023
	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.03)
Rain deviation rainy s. $_{t-1}$	-0.033			-0.107**			0.006		
	(0.05)			(0.04)			(0.04)		
Rain deviation dry s. $_{t-1}$	-0.082**			-0.009			-0.061*		
	(0.04)			(0.04)			(0.03)		
Temp deviation rainy s. $_{t-1}$	0.117*	0.120*		0.069	0.091		0.066	0.062	
	(0.07)	(0.07)		(0.07)	(0.07)		(0.05)	(0.05)	
Temp deviation dry s. $_{t-1}$	-0.025	-0.013		-0.070	-0.076		0.029	0.041	
	(0.05)	(0.05)		(0.06)	(0.06)		(0.04)	(0.04)	
Positive rain deviations $_{t-1}$ - rainy s.			-0.030			-0.072			-0.008
			(0.06)			(0.05)			(0.05)
Negative rain deviations $_{t-1}$ - rainy s.			-0.034			-0.178*			0.040
			(0.09)			(0.11)			(0.08)
Positive rain deviations $_{t-1}$ - dry s.			-0.017			0.019			-0.011
			(0.04)			(0.05)			(0.04)
Negative rain deviations $_{t-1}$ - dry s.			-0.227***			-0.050			-0.178**
			(0.09)			(0.09)			(0.07)
Positive temp deviations $_{t-1}$ - rainy s.			0.077			0.034			0.060
			(0.08)			(0.08)			(0.06)
Negative temp deviations $_{t-1}$ - rainy s.			0.256**			0.210			0.101
			(0.11)			(0.13)			(0.08)
Positive temp deviations $_{t-1}$ - dry s.			-0.046			-0.110			-0.002
			(0.07)			(0.08)			(0.06)
Negative temp deviations $_{t-1}$ - dry s.			-0.009			-0.028			0.074
			(0.08)			(0.09)			(0.05)
N	448	448	448	448	448	448	448	448	448

Standard errors corrected for autocorrelation and spatial correlation in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$