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A Geospatial Analysis of Climate Change's Impact on Migration Among Vulnerable Agricultural Producers

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Abstract

This paper investigates how social policies influence the coping strategies of vulnerable agricultural households facing climate change. In particular, we examine how the Brazilian *Bolsa Família*, a Conditional Cash Transfer (CCT) program, affects relocation decisions among individuals whose incomes are directly impacted by extreme and severe droughts. Moving beyond traditional analyses based on administrative units, we track individual-level mobility using the geographical coordinates of household addresses, capturing both intra- and inter-municipal moves. These data are linked to high-resolution precipitation records from the CHIRPS dataset, with a grid size of 0.05° by 0.05° (approximately 31 km^2 or 12 mi^2). Using a panel of millions of individuals observed from 2015 to 2020, we find that short-distance relocations (within municipalities) are five times more common than long-distance migrations (between municipalities). Estimates from a Poisson panel model with fixed effects and time-varying controls indicate that social transfers significantly influence migration behavior. Individuals exposed to extreme droughts (top 1%) are 6% more likely to relocate, using CCT benefits to facilitate movement. In contrast, those affected by less intense but still severe droughts (top 10 to 1%) are 5% less likely to move, instead relying on the benefits to cope locally. These patterns remain robust across a range of model specifications and hold even when the analysis is restricted to benefit holders, suggesting that relocation decisions are made at the household level in these contexts. However, this buffering role of social protection also implies that vulnerable individuals are more likely to remain in areas with lower levels of socioeconomic infrastructure than their migrating peers.

1 Introduction

Climate change has been associated to a rise in the frequency and severity of extreme natural events, resulting in significant economic and human losses globally (Dilley et al., 2005; Pindyck and Wang, 2013; Acharya et al., 2023). This situation is particularly dire for socioeconomically disadvantaged households, as climate change is projected to exacerbate existing vulnerabilities and inequalities (Hallegatte et al., 2017; Otto et al., 2017). One of the critical consequences for individuals in social and climate vulnerability is a heightened risk of displacement due to extreme weather events (Morrow-Jones and Morrow-Jones, 1991; Hallegatte et al., 2016). In this context, social policies and safety net programs may help vulnerable populations navigate migration decisions.

This research examines how social policy affects individual relocation decisions among vulnerable agricultural households in Brazil. Specifically, we investigate how the Conditional Cash Transfer (CCT) program *Bolsa Família* (BFP) influences household responses to income shocks from extreme and severe drought-induced crop losses. By focusing on the interplay between climate-related stressors and social protection, we aim to understand the extent to which social policy may mitigate the need for migration as a coping strategy. To precisely identify individual mobility and exposure to extreme weather events, we developed a novel methodology that links relocation patterns, both within and between Brazilian municipalities, using the geographical coordinates of household addresses and high-resolution historical precipitation data at fine spatial grids.

Using panel data from 2015 to 2020, we observe that 20% of individuals in vulnerable agricultural households migrated at least once over a three-year period. Short-distance relocations, those occurring within the same municipality, were five times more common than between municipalities moves. The interaction between access to social benefits, *Bolsa Família*, when exposed to drought events categorized as severe (those between the 10% and the 1% of the distribution) lead to a reduction in relocation probabilities: 5% in the first year, 4% over the next two years, and 5% across the full three-year period, with stronger effects again concentrated in short-distance moves. In contrast, receiving social benefits while faced with an extreme drought event (those in the 1% extreme of the distribution) significantly increases the likelihood of relocation. The probability of moving rises by 6% in the first year and by 3% over two years, primarily driven by within-municipality moves. These effects remain robust in linear OLS estimations and persist when the analysis is restricted to benefit holders, suggesting that relocation decisions in these contexts are made at the household level. However, individuals who remain in place tend to live in areas with weaker socioeconomic infrastructure than those who relocate.

Migration is one of the most common response mechanisms used by vulnerable individuals to withstand the consequences of extreme weather events (Berlemann and Steinhardt, 2017; Hunter, 2005; Ober, 2019). While safety net and social policy have significant importance for vulnerable households that have reduced access to traditional financial and non-financial responses to income-shocks (Dercon, 2002). The economic implications of resilient social policies are profound. By investing in adaptive capacity, governments can reduce the long-term costs associated with climate impacts. Therefore, social policy plays a central role in enhancing household resilience to the multifaceted challenges posed by climate change. Safety nets that incorporate climate risk considerations not only protect against immediate shocks but also promote long-term development goals.

Accordingly, the association between CCTs and migration decisions has been of great interest in the literature (Adhikari and Gentilini, 2018; Hagen-Zanker and Himmelstine, 2012; Stecklov et al., 2005; Cirillo, 2018). While programs that focus on local strategies of implementation tend to reduce migration, broader and universal programs may induce mobility. In Brazil, this association has been studied at the municipality level by Oliveira and Chagas (2018) and Silveira Neto (2008), with results suggesting that CCTs reduce individual probability of migration. However, research in this area often overlooks individual relocation patterns within administrative regions, which limits our understanding of this phenomenon. We not only develop a new methodology to address this gap, but we also connect our findings to the challenges posed by climate change.

2 Climate Change, Social Policy and Migration

In recent years, the interplay between social policy and household resilience has garnered increasing attention, particularly in the context of socioeconomic vulnerabilities exacerbated by climate change. Cash transfer programs have emerged as a component of social policy able to bolster resilience among low-income households in developing countries.

These programs provide direct financial assistance to households, enabling them to manage immediate economic pressures while investing in adaptive strategies, particularly in rural areas where access to formal financial services is limited. This diversification is particularly important in regions facing increased climate risk, as it enables producers to buffer against crop failures or market fluctuations.

2.1 The Brazilian scenario

The Brazilian scenario is highly representative of such (WB, 2021). Between 2015 and 2020, approximately 14 million individuals lived in vulnerable agricultural households, beneficiaries from both social and agricultural programs.[1] Given the current technological standards, climate change is projected to reduce agricultural output per hectare in Brazil by 18% (Assunção and Chein, 2016). This decline is likely to lead to increased displacement of vulnerable populations.

In fact, data from the Brazilian specialized authorities, from the S2iD system, shows that 90% of recognized natural disasters in the Brazilian territory were hydrological instances, caused by either insufficient rainfall or excessive precipitation. Table 1 highlights the two primary natural disasters linked to rainfall scarcity: dry spells and droughts. Notice that drought instances, recognized by the Brazilian authority, affected up to 7% of municipalities in certain years.

There are, indeed, specific climatic characteristics of the Brazilian regions that make

[1]Members of families registered both on the CadÚnico and DAP/Pronaf programs.

Table 1: Drought and Dry Spell occurrences in Brazilian municipalities as acknowledge by the governmental authorities between 2015-2019

N of Municipalities	Dry Spell	Drought
2015	843 (15%)	394 (7%)
2016	802 (14%)	370 (7%)
2017	109 (2%)	44 (1%)
2018	100 (2%)	132 (2%)
2019	37 (1%)	43 (1%)

Notes: Authors, with data from the Integrated System of Information on Disasters (S2iD) and historical data on Federal Recognition of Emergency Situations and Public Calamity provided by the Ministry of Regional Integration and SEDECs.

them more susceptible to such events. For instance, the Northeastern region, of semi-arid and arid climate, accounts for almost 80% of the cases of drought and dry spell phenomenons. As a result, there are existing government programs designed to help communities in these areas cope with exposure to extreme natural events, such as the *Garantia Safra* and the First and Second Water Cisterns programs (CP1A and CP2A) (Bobonis et al., 2022; Da Mata et al., 2023). Additionally, special funds have been allocated to assist affected populations, covering approximately 20% of the cases between 2015 and 2020.

The following sections present how we developed our methodology for analyzing individual migration patterns across the Brazilian territory in association with high-resolution historical precipitation data. We will then present a basic model for individual migration along with our estimations. First, however, we will introduce the datasets utilized in these analyses.

3 Data

In this section, we present the data sources used to construct our methodology for observing individual relocation in association with the historical precipitation index. We combined administratively restricted data with publicly available information from multiple sources concerning low-income individuals and households in Brazil.

3.1 *Cadastro Único* (CadÚnico)

The *Cadastro Único para Programas Sociais*(CadÚnico)[2] of the Federal Government is a database that identifies and characterizes the universe of low-income households in Brazil.[3] It was created by the Decree No. 3,877/2001 (Brasil, 2001), structured within the Ministry of Social Development[4] in 2001. Over the decades, CadÚnico has emerged as an important tool in supporting public policies design aimed at improving the lives of the low-income households. It provides managers with information on the risks and vulnerabilities to which the poor and extremely poor population of Brazil is exposed to.

In 2012, the system underwent a major improvement after Ordinance No. 177/2011 (Brasil, 2011). The information on Bolsa Família Program beneficiaries was, then, restructured within version 7 of CadÚnico, a newer and better connected infrastructure. Thus, it began to include a wider range of socioeconomic and demographic variables of registered households and individuals. Particularly important for our analysis, the introduction of the address information for each household. However, this information was not fully registered since the beginning. For instance, there is no address information for 42% of the households in 2012. It only significantly improved by 2015, when 96% of the households presented reliable address information; from 2016 onward, missing addresses were less than 1% of the households. Thus, we decided to use active records for households and individuals from 2015 until 2020, period of highly reliable data.

3.2 *Declaração de Aptidão ao Pronaf* (DAP/Pronaf)

The *Declaração de Aptidão* (DAP) *ao Programa Nacional de Fortalecimento da Agricultura Familiar* (*Pronaf*)[5], is a federal government administrative record that identifies and qualifies

[2]Unified Registry for Social Programs, in free translation

[3]Low-income households are defined as those with a monthly *per capita* income of up to half the current minimum wage or a total household income of up to three times the minimum wage.

[4]Between the years 2019 and 2022, it was called the Ministry of Citizenship.

[5]Declaration of Aptitude (DAP) for the National Program for Strengthening Family Farming (Pronaf), in free translation

Family Agricultural Production Units and their organized associative forms of Brazil. The DAP system identifies family farmers and beneficiaries of agrarian reform who can apply for rural credit and access to other government programs. We use DAP information to identify vulnerable individuals and households whose primary income is derived from crop production, making them particularly susceptible to the significant impacts of extreme drought on household income. Their climate and socioeconomic vulnerability is underscored by the fact that all of them are also registered in the *CadÚnico* for social programs.

3.3 CHIRPS: *Climate Hazards Group InfraRed Precipitation with Station data*

The Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) (Funk et al., 2015) is a 43 plus years quasi-global daily, pentadal, and monthly precipitation dataset. Spanning 50^o S - 50^o N (and all longitudes) and ranging from 1981 to near-present, CHIRPS incorporates the climatology, CHPclim, 0.05^o resolution satellite imagery, and in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring. CHIRPS was developed to support the United States Agency for International Development Famine Early Warning Systems Network (FEWS NET). Building on approaches used in successful thermal infrared (TIR) precipitation products and current state-of-the-science interpolated gauge products, CHIRPS uses a "smart interpolation" approach, working with anomalies from a high resolution climatology.

We use monthly precipitation information at the grid-level of 0.05^o[6] for the Brazilian territory between January 1981 to December 2019 to develop a standardized historical precipitation index for each household address in our sample.

[6] 0.05^o = 5.55 km or 3.44 miles, approximately.

3.4 Sistema Integrado de Informações sobre Desastres (S2iD)

The *Sistema Integrado de Informações sobre Desastres* (S2iD)[7] is a national dataset compiled by the Ministry of Regional Integration of the federal government.[8] It works as a platform of the National Civil Protection and Defense System, integrating various systems from the National Civil Protection and Defense Secretariat (Sedec). Its aim is to enhance and provide transparency in risk and disaster management in Brazil through the digitization of processes and the availability of systematized information and resources. We used S2iD data to control for the occurrence of any publicly acknowledged weather disaster in the Brazilians municipalities between 2015 and 2020.

3.5 Garantia Safra

The *Garantia Safra*[9] is an initiative within the Pronaf aimed at ensuring minimum living conditions for family farmers in municipalities that are systematically subject to severe crop losses due to drought or excessive rainfall. It works as a subsidized insurance, which rural producers, local- and higher-levels governments contribute to a fund available to cover confirmed crop losses due to extreme weather events. We use *Garantia Safra* information as a control for other governmental programs that may be linked to individual exposure to extreme drought and the benefits provided by social programs.

3.6 Portal da Transparência

The *Portal da Transparência*[10] is a Brazilian government portal dedicated to making public all expenditures of the federal government. It lists all expenses and cash transfers the federal government, including the individuals receiving social benefits, such as the *Bolsa Família* and the *Garantia Safra*, and how much they have received.

[7]Integrated Disaster Information System, in free translation.

[8]This dataset was made available by the ministry through a Freedom of Information Act (LAI) process, number 59016.001820/2022-14.

[9]Crop-Guarantee, in free translation.

[10]Transparency Portal, in free translation: https://portaldatransparencia.gov.br/download-de-dados

4 Methodology

One of the biggest concerns over the geospatial analysis of climate change and extreme natural events is the ability to observe affected units with high precision. Previous work relied on observation at the municipality-, county-, or district-levels, which misses a lot of variation for individual and household analysis (Cattaneo et al., 2019). In this paper we develop a new methodology which is able to overlap each place of residence (at the street level) of vulnerable households members and historical precipitation associated to small grids of 0.05° by 0.05° (approximately 31 km^2 or 12 mi^2).[11] The high-resolution grids of precipitation data, combined with the proximity of agricultural producer families to their crop fields, enable us to accurately estimate the impact of extreme weather events on their income.

The following subsections detail our process for retrieving the geographic coordinates (latitudes and longitudes) of all vulnerable households in the *CadÚnico* between 2012 and 2020. We then explain how we overlapped this data with the historical precipitation index from the CHIRPS project using geographic information tools. An example of the monthly snapshots with geographical points associated with the precipitation data can be observed in Figure 1.

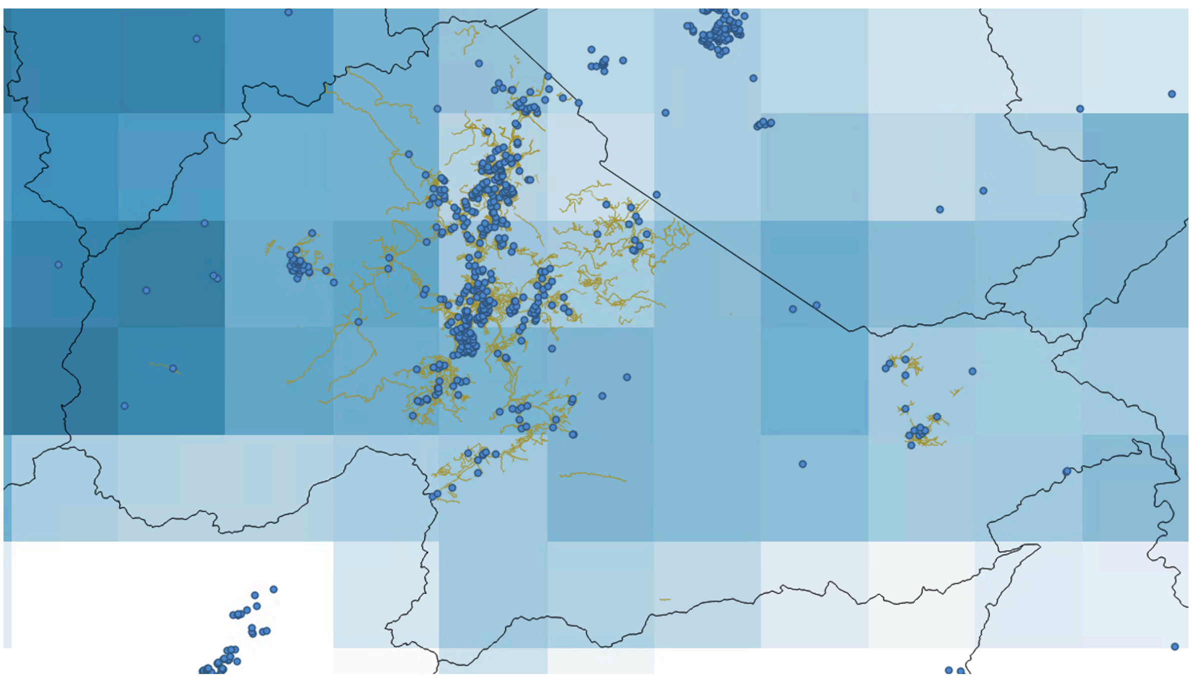
4.1 Retrieving the geographical coordinates of households' addresses

We retrieved the geographical coordinates for the entire period of *CadÚnico* data available from 2012 to 2020, although we decided to include only data from 2015 until 2020 in our sample, as explained in Subsection 3.1. We began by concatenating all available address location information for each year in the *CadÚnico* household datasets.[12] Next, we combined the datasets from 2012 to 2020, ensuring that each identical entry was represented only

[11] The same methodology is applied in our paper with preliminary title "Resilience in Adversity: How Social Policies Amend Labor and Capital Mobility in the Face of Extreme Weather Events" in collaboration with the UNU-WIDER and IMDS.

[12] Variables: $cod\_munic\_ibge\_fam$, $nom\_localidade\_fam$, $nom\_tip\_logradouro\_fam$, $nom\_tit\_logradouro\_fam$, $nom\_logradouro\_fam$ + the name of the municipality and state.

Figure 1: Household units and CHIRPS precipitation index for the city of Nova Friburgo, RJ/Brazil



Notes: The authors, with data from the CHIRPS project and *CadÚnico* in the QGIS software. Blue dots are the geographic coordinates of household's addresses, in yellow the streets covered by IBGE in the Census, in black the municipality's territory limits, and in shades of blue squares the precipitation index for each grid and month/year.

once, along with the relevant variables. This resulted in a dataset with 14,701,031 uniquely identified addresses, which we then processed through the HERE platform's Geocode algorithm to obtain the most accurate latitude and longitude coordinates.

Table 2 presents summary statistics of the quantity and quality of this methodology by groups of municipalities. We were able to retrieve geographic coordinates for 99.3% of the addresses. Among these, only 15% were accurately matched to the municipality's geocentric coordinates by the algorithm, while the remaining 85% matched within-municipality locations. Even more importantly, 77% are at street level.

After a thorough analysis, we concluded that the quality of information provided by end-users correlates directly with the municipality size; smaller towns with larger rural areas tend to present greater challenges for the algorithm find street-level address geographic coordinates approximations. This is a result of the quality of the data registered in the *CadÚnico* system and the territorial coverage of the HERE algorithm. In many cases, we were unable to retrieve a more accurate address placement due to improper registration of street address information by end-users or the algorithm's inability to find a perfect match within the available datasets.

Table 2: Geocoding of households' unique addresses in the 2012-2020 *CadÚnico*

Groups	Capitals		Inhab. > 100,000		40k < Inhab. < 100k		15k < Inhab. < 40k		Inhab. < 15k		**Total**	
Addresses	N	%	N	%	N	%	N	%	N	%	N	%
Processed	2,227,957	100%	3,918,161	100%	2,676,148	100%	3,406,160	100%	2,472,605	100%	**14,701,031**	**100%**
Geocoded	2,221,164	99.7%	3,899,134	99.5%	2,652,450	99.1%	3,375,225	99.1%	2,452,639	99.2%	**14,600,612**	**99.3%**
Not found	6,723	0.3%	19,027	0.5%	23,698	0.9%	30,935	0.9%	19,966	0.8%	**100,349**	**0.7%**
Quality of the Geocoding												
Street or similar	1,958,402	88%	3,359,339	87%	2,121,535	80%	2,332,668	69%	1,421,619	57%	**9,751,466**	**77%**
Locality:	262,832:	12%:	539,795:	14%:	530,915:	20%:	1,042,557:	31%:	1,031,020:	42%:	**3,407,119:**	**23%:**
Postal Code	41,984	2%	87,745	2%	33,691	1%	35,353	1%	29,549	1%	**228,322**	**2%**
District	181,939	8%	303,972	8%	137,365	5%	159,142	5%	134,944	6%	**917,362**	**6%**
Municipality	38,909	2%	148,078	4%	359,859	14%	848,062	25%	866,527	35%	**2,261,435**	**15%**

Notes: Authors, with household data from the *CadÚnico* for Social Programs from 2012-2020. HERE Platform Geocoding API. The quality analysis conveys the information from the output variable retrieved from the HERE Geocoding algorithm.

4.2 Associating the Precipitation Index with Household Addresses

We linked the precipitation index to the geographic coordinates of vulnerable households to analyze how variations in precipitation impact household income, particularly in the context of extreme weather events. First, we imported the historical precipitation data from the CHIRPS project into the QGIS software. This dataset contains high-resolution (0.05° by 0.05°) precipitation measurements from January 1981 until December 2019. We then overlaid the precipitation data onto the geographic coordinates of the households. Using spatial analysis tools in QGIS, we extracted precipitation values for each household based on their geographic location. This allowed us to create a comprehensive dataset that includes not only household coordinates but also corresponding historical precipitation data, facilitating our subsequent analysis of the effects of extreme weather on income and migration patterns. By associating these two datasets, we can better understand the relationship between precipitation extremes and the socioeconomic vulnerabilities of the affected populations.

As an example, Figure 2 presents the CHIRPS precipitation data (squares in shades of blue) for the Brazilian territory with the municipalities' administrative borders in brown and the geographical distribution of vulnerable agricultural households in red dots for January 2019.

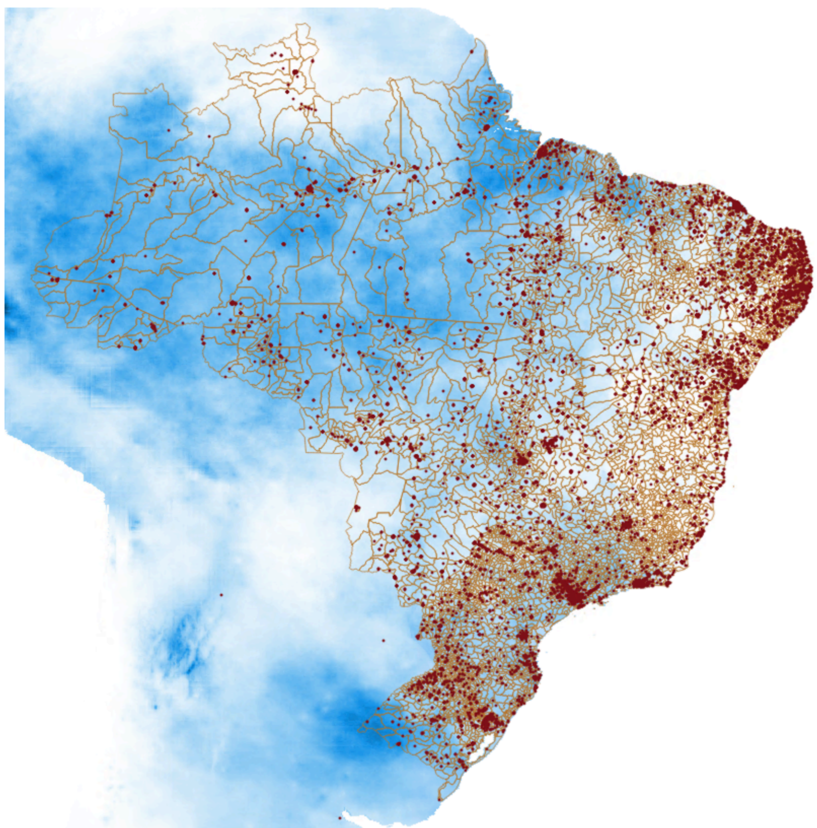
4.3 A Standardized Historical Precipitation Measure

We build on Bobonis et al. (2022), Hidalgo et al. (2010), and Lazzari et al. (2024) a standardized precipitation measure based on historical precipitation in the grid (area) of interest - the region where a household's address is located, for each month of the year. Differently from them, however, we develop this historical precipitation assessment at the smallest area possible, the grids of size 0.05° by 0.05° from the CHIRPS datasets.[13]

This historical assessment is crucial for enabling meaningful comparisons across areas with different climatic baselines. Following Bobonis et al. (2022), we define extreme natural events based on standardized deviations from historical norms: specifically, as the differ-

[13]We exploit two distinct phenomena with the precipitation index based on the heterogeneous effects of rainfall on agricultural and urban areas. The first case is analyzed in this paper; the second one exploits high volumes of rainfall in short periods of time. The latter has is forthcoming with preliminary title "Resilience in Adversity: How Social Policies Amend Labor and Capital Mobility in the Face of Extreme Weather Events" in collaboration with the UNU-WIDER and IMDS.

Figure 2: CHIRPS precipitation index for January 2019 - Brazil



Notes: Author's elaboration with data provided by the CHIRPS project and *CadÚnico* with the QGIS software.

ence between the current period's precipitation index and the historical mean for the same period, divided by the grid-level historical standard deviation. This approach accounts for local climatic variation and allows for a relative measure of weather extremes.

In line with Corbi et al. (2024), we construct a proxy for weather shocks based on cumulative rainfall during Brazil's main crop-growing season, spanning from spring (November) to autumn (April)—a critical window for agricultural productivity.[14] The other uses yearly cumulative rainfall over an area. The standardized index is computed as follows:

$$\text{Standardized Precipitation}_{g,t} = \frac{(Precipitation_{g,t} - \overline{Precipitation}_{g,t})}{\sigma_{g,t}}$$

where $Precipitation_{g,t}$ refers to precipitation in grid g in time period t (a Growing Season or year); $\overline{Precipitation}_{g,t}$ refers to the average historical precipitation in grid g and time period t; and $\sigma_{g,t}$ is the historical standard deviation of precipitation in grid g and time period t.

This measure is useful to assess the extent to which the precipitation index over the Growing Season GS or year y was historically extreme. It's important to note that our standardized index is based on historical deviations for each grid and time period. For longer periods, we employ a similar strategy by calculating the cumulative precipitation for the same months across different years. For example, the cumulative precipitation in grid g is derived from the sum of precipitation between years t and t-1.

5 Relocation decisions

We begin the analytical section of this paper by presenting a simple model of individual relocation decision-making. Relocation decisions in the context of climate change involve a complex interplay of socioeconomic and behavioral factors (Black et al., 2011; Martin et al.,

[14]The growing season (GS) is very similar for different regions of Brazil. We use the months between November and April as an approximation:

$$Precipitation_{g,GS} = \sum_{m \epsilon [Nov,Apr]} Precipitation_{g,m}$$

2014). Nevertheless, migration remains one of the most common strategies for vulnerable individuals to cope with the impacts of extreme natural events (Berlemann and Steinhardt, 2017; Hunter, 2005; Ober, 2019). Economic hardship, along with direct income and wealth losses resulting from these events, is identified as a primary driver of migration, particularly for households facing climate and economic vulnerability. Consequently, social protection policies hold significant potential for enabling vulnerable individuals to adapt and develop resilience strategies in response to climate shocks. (Cattaneo et al., 2019; Premand and Stoeffler, 2020).

We outline a locational choice model where the relocation decisions is a function of both financial and non-financial factors, along with a random shock component, as follows:

$$Relocation\ Decision_{i,t} = f(I_i, S_i, C_i, \varepsilon_{i,t})$$

where $Relocation\ Decision_{i,t}$ is the individual i decision to migrate or not assessed in time t. This assessment is a comparison between financial factors, as income I and social benefits S, and non-financial factors, as community links C. A key component for our analysis is the random shock ε, such as an extreme natural event. We are mostly interested in understanding the relationship between the random shock component and financial factors on migration decisions.

6 Empirical Strategy

The relocation model presented in section 5 is applied to the migration decision-making of vulnerable agricultural households exposed to extreme weather events. Take a scenario where crop output, highly dependent on precipitation, is the main income source of a vulnerable family firm;[15] they are beneficiaries of social programs, such as the BFP; preferences for non-financial factors are fixed over short periods of time; and they are subject

[15] Rainfall indices are vastly used as proxies for rural household's income in the literature, as seen in (Hidalgo et al., 2010; Jayachandran, 2006; Dell et al., 2014).

to the occurrence of extreme weather events.

We rely on the hypothesis that extreme negative deviations from the historical precipitation, i.e. drought intensity, over a grid/residence are quasi-random events. Consequently, exposure to high instances of drought is considered an unanticipated negative shock to agricultural productivity. To reinforce this assumption, we also account for longer periods of cumulative precipitation up to years *t*-1 and *t*-2.

We estimate the reduced-form equation of the relationship between being a social program beneficiary and exposure to extreme natural events in a panel of vulnerable agricultural individuals between the baseline year *t* and the following periods *t*+1 and *t*+2, as follows:

$$\begin{aligned} Relocated_{\,i,t+n} = \alpha_{i,t} &+ (Bolsa\ Familia\ *\ Extreme/Severe\ Drought)'_{i,t}\ \beta + \\ &+ \gamma\ Bolsa\ Familia_{i,t} + (Extreme/Severe\ Drought)'_{i,t}\ \eta + \\ &+ Cumulative\ Historical\ Neg.\ Std.\ Precipitation)'_{i,[t,t-1,t-2]}\ \Omega + \\ &+ \theta\ Income_{i,t} + \mathbf{X}'_{i,t}\ \Delta_1 + \mathbf{HH}'_{i,t}\ \Delta_2 + \mathbf{M}'_{i,t}\ \Delta_3 + \mathbf{O}'_{g,t}\ \Delta_4 + \phi_i + \rho_t + \epsilon_{i,t} \end{aligned}$$

where $Relocated_{i,t+n}$ is a dummy variable that assumes the value of 1 if the individual *i* relocated any time in the following *t*+*n* years, taken as a probability;[16] The coefficients of interest β conveys the association between the individual being a beneficiary of the Bolsa Familia Program and their exposure to extreme (1%) or severe (10% to 1%) drought instances as a dummy variable (in quantiles of the historical rainfall distribution) in year *t*. Thus, the terms $Bolsa\ \ Familia_{i,t}$ and $Extrene/Severe\ \ Drought_{i,t}$ are individual components of the mentioned interaction, respectively. Cumulative Historical Neg. Std. Precipitation$_{i,[t,t-1,t-2]}$ the cumulative rainfall for the year *t*, and the previous years *t*-1 and *t*-2, measured as continuous variables in Standard Deviations of the Distribution of the negative precipitation index historically assessed for a grid unit. $\mathbf{X}_{i,t}$ the matrix of time-varying controls containing the

[16]Relocation is assessed cumulatively for one, two, or three years after the baseline year *t* if the geographic coordinates of the address registered in each year for each individual in the *CadÚnico* changed.

individual characteristics in year t, including, for instance, educational level and individual income; $\mathbf{HH}_{i,t}$ the matrix of time-varying controls containing the household characteristics in year t, including, for instance, average income and residence characteristics; $\mathbf{M}_{i,t}$ the matrix with information on any natural disasters acknowledge by the federal authorities from the S2iD dataset; $\mathbf{O}_{g,t}$ the matrix of time-varying controls containing average characteristics of the households located in the same geographic coordinates of origin g in year t; ϕ_i the individual fixed effects; ω_t the year fixed effects; and $\epsilon_{i,t}$ the idiosyncratic error term. All estimations are clustered at the panel unit of analysis, individuals.

We should expect that β is a robust estimate of the causal effect of social policy benefits and exposure to climate change's effects on relocation decision, given the quasi-random occurrence of extreme natural events. Exposure to drought is measured at both the intensive and the extensive margins, based on historical conditions for each grid/area. As a result, farmers cannot predict the extent of drought exposure in any given year. This uncertainty helps explain why half of our sample migrates in the first year following a major drought event. At the same time, the comparison groups are very similar vulnerable households registered in the *CadÚnico* for social benefits. Beneficiaries and non-beneficiaries of the *Bolsa Familia* differ by a small margin given the program's eligibility criteria.

7 Observed units

For the empirical analysis we wanted to observe as close as possible the universe of vulnerable agricultural producers in Brazil, their household addresses and exposure to extreme natural events. We have special interest in the small, family units, the most exposed to negative income shocks, stemming from effects of climate change. After observing that the occupational information from family-members registered in the *CadÚnico* was not optimal for such,[17] we managed to link the *CadÚnico* datasets with the DAP/Pronaf, a registry

[17]For instance, we should be able to observe with variable "ind_parc_mds_fam" agricultural and agrarian reform households. However, many of those are not listed as agricultural producers in the corresponding occupation variables "cod_agricultura_trab_memb" and "cod_principal_trab_memb".

of vulnerable agricultural household producers maintained by the Ministry of Agrarian Development and Family Agriculture. Notwithstanding, we were able to find all of the benefit holders in DAP/Pronaf between 2015 and 2020 also in the *CadÚnico* by using their social security number (CPF) as the key. This way, we secured a match between the universe of social program beneficiaries that are vulnerable agricultural producers. All other datasets were merged by individual and/or administrative territory for the analysis, with close to perfect matching results.

We took a few steps to select our final sample. Firstly, we restricted the *CadÚnico* sample for only household units with "active" entries, so we guarantee the record is up-to-dated and with reliable information.[18]. Then, we compiled the information in DAP/Pronaf by observing any individual, benefit holder of secondary, who was ever registered between 2012 and 2020.[19] Given the household structure of benefits, we kept in our sample any individual member of households in which at least one member was listed in DAP/Pronaf. Finally, we keep in our analysis only individuals observed in the resulting dataset for more than one year in our panel, in order to observe migration by comparing their addresses over time.[20]

8 Summary Statistics

The sample of individuals in vulnerable agricultural households has 55,213,451 observations of 14,362,945 unique individuals across the years 2015 and 2020, which 76% were beneficiaries of the BFP. Of those, 26,793,027 observations were from the 6,661,156 unique individuals directly found in DAP/Pronaf as main benefit holders.[21] Notice that we can only observe

[18]This is important to observe only those actively receiving social benefits and with non-missing address information, which were, on average, less than 1% over the 2015-2020 years.

[19]We use the information back to 2012, because the DAP/Pronaf dataset contains only the stock of information ever registered in the system and entries were updated on a biannual basis.

[20]Notice that we are not able to observe individuals who left the *CadÚnico* over the years. This could lead to censored-data bias to our estimates. However, we observe an average migration rate similar to that of the Brazilian Census and to what is found in the literature (Oliveira and Chagas, 2018).

[21]There was missing information for some individuals among those who migrated between and within municipalities in very few instances.

the migration status of individuals in t+1 years between 2015 and 2019; in t+2 years between 2015 and 2018; and t+3 years between 2015 and 2017.

Moreover, one of the main contributions of our analysis is to observe individual relocation across the territory, not restricted to administrative areas. Table 3 presents the average share of individuals in our panel who migrates in t+1, t+2, and/or t+3 years after the baseline year t,[22] when exposure to extreme drought is assessed. We constructed three outcome variables as migration assessments: "Moved Out", which compares the geographical coordinates of individual's household addresses between time periods; "Within": compares the geographical coordinates of individual's household addresses conditional on belonging to a same municipality; and "Between": compares the geographical coordinates of individual's household addresses conditional on belonging to different municipalities. It is striking to observe that migration within a municipality's territory is five times higher than longer-distance ones to a different municipality.

Table 3: Individual migration of vulnerable agricultural producers between t and t+n, panel 2015-2020

Relocated between t and:	t+1			t+1 / t+2			t+1 / t+2 / t+3		
Address changed	Moved Out	Within	Between	Moved Out	Within	Between	Moved Out	Within	Between
				any member of the family					
Share of ind. (in %)	7%	6%	1%	14%	12%	2%	20%	17%	3%
N of ind. (in millions)	3.81	3.21	0.60	6.18	5.27	0.91	6.68	5.74	0.94
				benefit holder					
Share of ind. (in %)	6%	5%	1%	12%	10%	2%	18%	15%	3%
N of ind. (in millions)	1.63	1.38	0.25	2.68	2.28	0.40	2.92	2.51	0.41

Notes: Authors, with data from the CadÚnico and DAP/PRONAF. Migration of individuals in vulnerable agricultural-producer families between 2015 and 2020. The columns stand for "Moved Out": addresses with different geographical coordinates between time periods; "Within": different geographical coordinates within a same municipality; and "Between": different geographical coordinates in different municipalities.

Although individuals more frequently migrate to areas of better socioeconomic and infrastructure than their places of origin, the same cannot be taken for granted for those displaced by extreme weather events. Table 4 presents the average characteristics of areas of origin and destination of vulnerable individuals exposed to the extreme (1%) and severe (10% to 1%) instances of drought and beneficiary of the BFP in our sample. We can observe that among those who migrated, they have indeed chosen places of better characteristics

[22] We take the cumulative instances of migration over the years.

than of their places of origin. However, individuals affected by extreme droughts tended to migrate to areas only marginally better than their places of origin, whereas those exposed to severe (but less extreme) droughts selected destinations that were comparatively better. This pattern can be understood by considering that extreme events may constrain decision-making, leaving affected individuals with fewer opportunities to optimize their relocation choices, unlike those facing milder shocks. Moreover, the data reveal the extent of this population's vulnerability: nearly half have access only to public water and waste collection services, while less than a quarter, on average, have access to a public sewage system.

Table 4: Test of the difference in means between the average characteristics of the locations of origin and destination of individuals who migrated between 2015 and 2020 - Beneficiaries of the BFP affected by extreme drought (1% of the distribution))

Drought Instance	Extreme (Top 1%)			Severe (Between Top 10% and 1%)		
Average of households	Destination	Origin	Difference (t-test)	Destination	Origin	Difference (t-test)
average per capita income (in BRL)	209.96	182.62	27.34***	190.60	166.41	38.71***
monthly household expenses (in BRL)	402.74	362.02	40.72***	376.95	338.25	38.70***
house with finished floor (share)	0.86	0.83	0.03***	0.89	0.87	0.02***
house with concrete finished walls (share)	0.49	0.48	0.01***	0.57	0.55	0.02***
access to public water provision (share)	0.48	0.47	0.01***	0.53	0.51	0.02***
access to public sewage system (share)	0.14	0.13	0.01***	0.17	0.15	0.02***
access to trash collection (share)	0.46	0.43	0.03***	0.47	0.43	0.04***
access to public energy system (share)	0.75	0.75	0.00**	0.80	0.79	0.01***
N of individuals	36,554	36,554		352,291	352,291	

Notes: Authors, with data from the CadÚnico and DAP/PRONAF. Comparison of origin-destination average characteristic of households located in a same geographical point for those in areas with the highest instances of drought: extreme (top 1%) and severe (top 10-1%).

9 Results

We begin by presenting in Table 5 and Table 6 our main results for the effect of the social benefits on individual relocation decisions in t+1, t+2, and t+3 years after an extreme/severe drought affected vulnerable agricultural producers between 2015 and 2020, as presented in Section 6.

We find that receiving *Bolsa Família* benefits while experiencing severe droughts (between the top 10% and 1% of the distribution) lead to a reduced likelihood of relocation: 5% lower in the first year, 4% over the next two years, and 5% across the three-year period.

These effects are primarily driven by moves within the individual's municipality of origin. In contrast, access to cash benefits while experiencing extreme drought events (top 1% of the distribution) increases the likelihood of individual relocation in subsequent periods: by 6% in the first year and 3% over the following two years. As before, these effects are concentrated in short-distance relocation within municipalities.

When focusing specifically on benefit holders within the household, the results remain consistent in both direction and magnitude. Cash transfers continue to exert a buffering effect, reducing the likelihood of relocation among those affected by severe drought, while increasing it in the face of extreme drought. Notably, for benefit holders exposed to severe droughts, cash transfers are associated with a 6% and 7% decrease in the probability of relocating to other municipalities in periods t+1 and t+2, respectively. These findings suggest that relocation is neither limited to nor primarily driven by the principal decision-maker or benefit holder alone. Rather, they reflect a collective household strategy, likely coordinated among members and shaped by shared exposure to environmental and economic stressors.

These results relate to and contribute to the literature in two main ways. First, drought severity is strongly associated with greater crop losses stemming from unanticipated income shocks. While social benefits can enable relocation by providing the financial means for highly exposed or displaced individuals, they may also help those less severely affected to build resilience and remain in place, mitigating moderate income losses from crop damage. Second, by distinguishing between the effects of severe and extreme drought events at the individual level, our analysis helps reconcile contrasting findings in the literature by revealing differences in treatment exposure and behavioral responses.

They also contribute to the broader literature on household migration and adaptation by emphasizing the collective nature of migration decisions in rural, vulnerable contexts. It resonates with models in which migration is treated as a household-level risk diversification strategy (Stark and Levhari, 1982), rather than an individual-level labor market choice. Under this framework, the role of social protection, such as conditional cash transfers, is to ease credit constraints and provide flexibility in how households allocate migration roles across members.

Although we take the Poisson panel models with fixed effects and time-varying controls as the best strategy to fit our model, see Wooldridge (1999) and Wooldridge (2000), we do also estimate OLS coefficients in a linear specification. The OLS results, reported in subsection A.3, are very similar to those of the Poisson model. Although relocation to other municipalities, have significant and positive treatment estimates, we cannot rule them out as being the result of biased and spurious estimates.

Table 5: Migration decisions of members of agricultural producer households in CadÚnico between 2015 and 2020: Effects of droughts by groups of extreme drought events and benefits of the BFP.

Dependent Variable	(1) Moved Out	(2) Within	(3) Between	(4) Moved Out	(5) Within	(6) Between
	any family member			*benefit holders*		
	relocation between t and t+1					
Bolsa Família * Extreme Drought	**0.0620**	**0.0567**	0.0806	**0.0782**	**0.0466**	0.0116
	(0.0132)	(0.0147)	(0.0335)	(0.0183)	(0.0101)	(0.0062)
	relocation between t and t+2					
Bolsa Família * Extreme Drought	**0.0341**	**0.0286**	0.0431	**0.0763**	**0.0377**	0.0022
	(0.0072)	(0.0080)	(0.0197)	(0.0204)	(0.0113)	(0.0069)
	relocation between t and t+3					
Bolsa Família * Extreme Drought	0.0110	0.0043	**0.0557**	0.0757	**0.0778**	**0.0702**
	(0.0044)	(0.0049)	(0.0131)	(0.0454)	(0.0271)	(0.0177)

Notes: Authors with data from the CadÚnico, DAP/PRONAF, and CHIRPS Precipitation. Precipitation in SDs for the Growing Season (Nov to Apr) at the grid level. Poisson panel estimations with fixed effects at the year and individual levels, time-varying controls for individuals, households, municipalities, and places of origin. Coefficient estimated for the effect of being a *Bolsa Família* beneficiary when affected by an extreme drought on the probability of migration of individuals in vulnerable agricultural-producer families between 2015 and 2020. The columns stand for "Moved Out": addresses with different geographical coordinates between time periods; "Within": different geographical coordinates within a same municipality; and "Between": different geographical coordinates in different municipalities. Standard errors are in parentheses, and estimated coefficients significant at the 1% level are shown in bold.

Table 6: Migration decisions of members of agricultural producer households in CadÚnico between 2015 and 2020: Effects of droughts by groups of severe drought events and benefits of the BFP.

Dependent Variable	(1) Moved Out	(2) Within	(3) Between	(4) Moved Out	(5) Within	(6) Between
	any family member			*benefit holders*		
	relocation between t and t+1					
Bolsa Família * Severe Drought	**-0.0538**	**-0.0634**	0.0055	**-0.0462**	**-0.0555**	**-0.0633**
	(0.0065)	(0.0071)	(0.0178)	(0.0089)	(0.0050)	(0.0034)
	relocation between t and t+2					
Bolsa Família * Severe Drought	**-0.0440**	**-0.0495**	-0.0144	**-0.0545**	**-0.0612**	**-0.0729**
	(0.0036)	(0.0039)	(0.0105)	(0.0098)	(0.0055)	(0.0037)
	relocation between t and t+3					
Bolsa Família * Severe Drought	**-0.0522**	**-0.0601**	0.0152	0.0041	-0.0263	0.0109
	(0.0024)	(0.0026)	(0.0077)	(0.0243)	(0.0144)	(0.0106)

Notes: Authors with data from the CadÚnico, DAP/PRONAF, and CHIRPS Precipitation. Precipitation in SDs for the Growing Season (Nov to Apr) at the grid level. Poisson panel estimations with fixed effects at the year and individual levels, time-varying controls for individuals, households, municipalities, and places of origin. Coefficient estimated for the effect of being a *Bolsa Família* beneficiary when affected by an severe drought on the probability of migration of individuals in vulnerable agricultural-producer families between 2015 and 2020. The columns stand for "Moved Out": addresses with different geographical coordinates between time periods; "Within": different geographical coordinates within a same municipality; and "Between": different geographical coordinates in different municipalities. Standard errors are in parentheses, and estimated coefficients significant at the 1% level are shown in bold.

10 Conclusion

This research finds that social policy plays a significant role in shaping the relocation decisions of vulnerable agricultural households affected by climate change. Our analysis shows that Conditional Cash Transfer benefits, by the *Bolsa Família* Program, affect the likelihood of migration following exposure to climate-related income shocks. For individuals affected by severe droughts (top 10% to 1% of the distribution), cash transfers reduce their likelihood of migration on 5%, on average, up to three years. In contrast, for those exposed to extreme (top 1%) drought instances, social benefits increases their probability of migration over the subsequent years in up to 6%. These effects apply similarly across all household members, indicating that the influence of social benefits on mobility decisions operates at the household level, rather than being concentrated among specific individuals. The results are also robust to alternative model specifications.

Our novel methodology allowed us to precisely identify individual migration patterns and exposure to extreme weather events across space and time. We found that 20% of vulnerable individuals migrated at least once between 2015 and 2020. Moreover, migration to nearby areas, within their municipality of origin, are five times greater than long-distance ones, to other municipalities. Those who receive social benefits tend to remain in areas with poorer socioeconomic infrastructure compared to their migrating counterparts.

These results help reconcile existing literature by demonstrating that social benefits, such as Conditional Cash Transfers (CCTs), can both increase or decrease individual relocation, depending on the nature of the shock and the characteristics of the affected individuals. On one hand, social benefits may facilitate migration by providing the financial means for those who are highly exposed or displaced to relocate. On the other hand, they can help less severely affected individuals absorb moderate income losses, such as those caused by crop damage, enabling them to remain in place. In this sense, cash benefits present a dual consequence: they can both support household resilience in the face of climate-related shocks and inadvertently discourage migration to areas with greater opportunities for social and economic advancement (Hallegatte et al., 2016).

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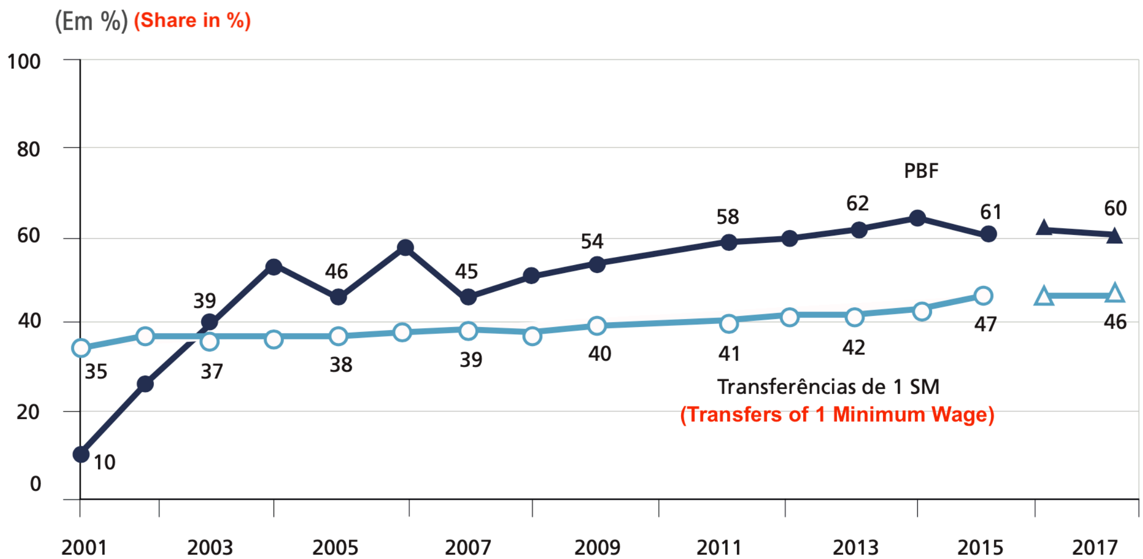
A Appendix

A.1 Summary Statistics - *CadÚnico*

Figure 3: Coverage of the Bolsa Família Program (BFP) and transfers equivalent to one minimum wage (Previdência and BPC) among the poorest 20% according to PNAD surveys (2001-2017)



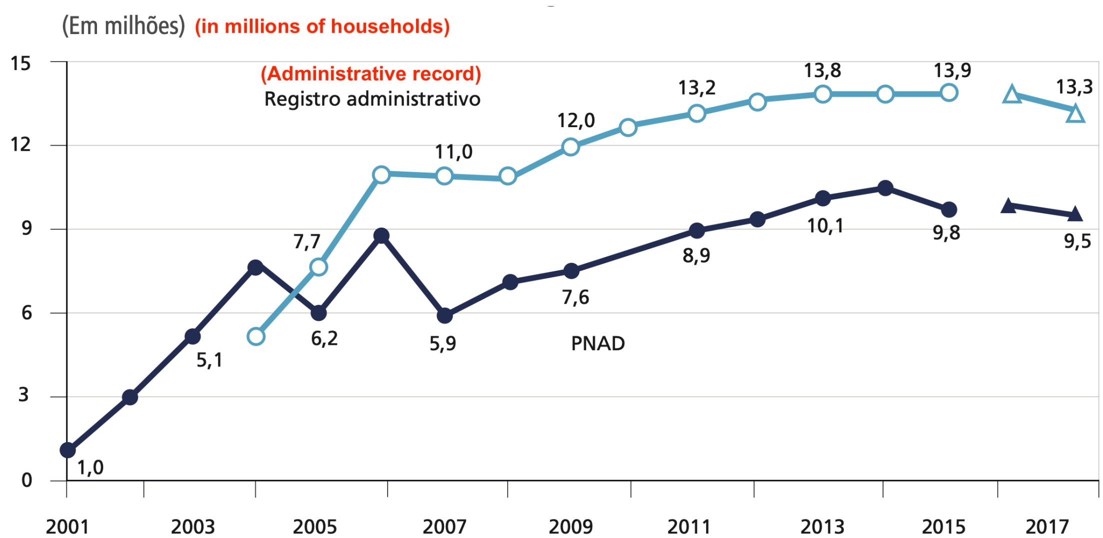
Source: Adapted from (Souza et al., 2019), graph 3, page 15. Created using data from PNAD surveys (2001-2015), Continuous PNAD surveys (2016-2017).
Note: PNAD information includes the predecessor programs of the BFP and excludes rural areas of the Northern states (except Tocantins) until 2003. The population among the poorest 20% was defined based on the net per capita household income of each benefit.

Table 7: Distribution of households/households according to registration status

households	2019	2018	2017	2016	2015	2014	2013	2012
Number of Obs.	53,187,644	48,770,064	44,112,029	40,015,875	37,612,900	35,439,014	32,897,119	30,243,128
Number of observations per registration status code (cod_est_cadastral_fam)								
in registration	13,663	42,970	53,378	19,001	21,474	30,052	42,670	31,483
without civil registration	951	1,368	2,197	3,200	2,921	2,579	1,915	1,410
registered	28,884,068	26,913,965	26,950,657	26,457,577	27,326,122	29,172,487	27,200,920	25,069,565
excluded	24,288,962	21,811,761	17,105,797	13,536,097	10,262,383	6,233,896	5,651,614	5,140,670

Notes: Own elaboration with data from the Unified Registry for Social Programs of the Federal Government and the Payroll of the Bolsa Família Program, from the Ministry of Citizenship/Social Development.

Figure 4: Households benefiting from the BFP in administrative records and PNAD surveys (2001-2017)



Source: Adapted from (Souza et al., 2019), graph 1, page 11. Created using data from PNAD surveys (2001-2015), Continuous PNAD surveys (2016-2017), and data from the Social Information Matrix of the Secretariat for Evaluation and Information Management (SAGI/MCidadania).
Note: PNAD information includes the predecessor programs of the BFP and excludes rural areas of the Northern states (except Tocantins) until 2003. Information from administrative records includes only the BFP and refers to September (2001-2015) and June (2016-2017).

Table 8: Distribution of individuals according to registration status

Individuals	**2019**	**2018**	**2017**	**2016**	**2015**	**2014**	**2013**	**2012**
Number of Observations	175,995,622	165,016,862	153,645,158	143,935,709	136,994,748	130,429,631	123,179,294	115,543,894
	Number of observations per registration status code (cod_est_cadastral_memb)							
in registration	21,344	57,641	70,109	28,182	39,751	41,850	64,146	44,659
without civil registration	8,997	11,678	18,794	26,150	31,310	30,985	23,474	13,384
registered	76,415,223	73,570,482	76,464,300	77,829,966	80,793,612	88,181,943	84,291,806	81,296,980
excluded	99,118,459	90,957,954	76,731,894	66,002,780	55,969,699	41,979,054	37,949,178	34,083,210
awaiting NIS attribution	2,141	64,957	75,444	48,630	56,600	38,418	19,617	9,425
awaiting characterization change	0	0	0	0	103,775	157,376	768,224	66,185

Notes: Own elaboration with data from the Unified Registry for Social Programs of the Federal Government and the Payroll of the Bolsa Família Program, from the Ministry of Citizenship/Social Development.

A.2 Poisson statistics

Table 9: First two moments of main dependent variables: Individual migration of vulnerable agricultural producers between t and t+n, panel 2015-2020

Migrated between t and:	t+1			t+1 / t+2			t+1 / t+2 / t+3		
Address changed	Moved Out	Within	Between	Moved Out	Within	Between	Moved Out	Within	Between
				any individual					
Mean	0.0703	0.0587	0.0114	0.1394	0.1181	0.0226	0.1959	0.1684	0.0316
Variance	0.0653	0.0553	0.0113	0.1200	0.1042	0.0221	0.1575	0.1400	0.0306
				benefit holders					
Mean	0.0620	0.0519	0.0101	0.1245	0.1058	0.0200	0.1770	0.1524	0.0280
Variance	0.0581	0.0492	0.0100	0.1090	0.0946	0.0196	0.1457	0.1292	0.0272

Notes: Authors, with data from the CadÚnico and DAP/PRONAF. Migration of individuals in vulnerable agricultural-producer families between 2015 and 2020. The columns stand for “Moved Out”: addresses with different geographical coordinates between time periods; “Within”: different geographical coordinates within a same municipality; and “Between”: different geographical coordinates in different municipalities.

A.3 OLS results

Table 10 presents the results for members of agricultural producer households affected by the extreme (1% highest) drought instances. Notice that the interaction between being a BFP beneficiary and exposure to these extreme drought instances has a significant positive effect on individual migration probability across all cases. Similarly, Table 11 shows the results for households affected by severe (between 10% and 1% highest) drought instances. Here, the interaction term is significant but reveals a negative relationship between social benefits and exposure to "less extreme" drought instances, with the exception of migration between municipalities, which shows a positive, though very small and not significant.

The results relate to and contribute to the literature in two main ways. First, drought severity is strongly associated with greater crop losses stemming from unanticipated income shocks. While social benefits can enable migration by providing the financial means for highly exposed or displaced individuals, they may also help those less severely affected to build resilience and remain in place, mitigating moderate income losses from crop damage. Second, by distinguishing between the effects of severe and extreme drought events at the individual level, our analysis helps reconcile contrasting findings in the literature by revealing differences in treatment exposure and behavioral responses.

A.4 Benefit Holders in Agricultural Producer Households

The previous analyses considered the migration behavior of all individuals in agricultural households affected by drought. However, one might argue that migration decisions are primarily driven by a key household member, typically the main income earner or social benefit holder, who plays a central role in navigating risk and allocating resources. To test this hypothesis, Table 12 presents the results for benefit holders, members of agricultural producer households exposed to extreme droughts (top 1%), while Table 13 reports results for those exposed to severe droughts (top 10% to 1%).

The results are similar to those found when analyzing all household members. Migra-

Table 10: Migration decisions of members of agricultural producer households in CadÚnico between 2015 and 2020: Effects of droughts by groups of extreme drought events and benefits of the BFP.

Precipitation in SDs for the Growing Season (Nov to Apr)	Moved Out	Within	Between
relocation between t and t+1			
Bolsa Familia * Extreme Drought	0.0047	0.0029	0.0019
	(0.0010)	(0.0009)	(0.0004)
Relative Effect (Δ % Mean Dep. Var. given β)	**7%**	**5%**	**17%**
relocation between t and t+2			
Bolsa Familia * Extreme Drought	0.0058	0.0029	0.0030
	(0.0011)	(0.0010)	(0.0005)
Relative Effect (Δ % Mean Dep. Var. given β)	**4%**	**5%**	**13%**
relocation between t and t+3			
Bolsa Familia * Extreme Drought	0.0030	0.0004	0.0030
	(0.0009)	(0.0009)	(0.0004)
Relative Effect (Δ % Mean Dep. Var. given β)	**2%**	0%	**10%**

Notes: Authors with data from the CadÚnico, DAP/PRONAF, and CHIRPS Precipitation. Precipitation in SDs for the Growing Season (Nov to Apr) at the grid level. OLS panel estimations with fixed effects at the year and individual levels, time-varying controls for individuals, households, municipalities, and places of origin. Coefficient estimated for the effect of being a *Bolsa Família* beneficiary when affected by an extreme drought on the probability of migration of individuals in vulnerable agricultural-producer families between 2015 and 2020. The columns stand for "Moved Out": addresses with different geographical coordinates between time periods; "Within": different geographical coordinates within a same municipality; and "Between": different geographical coordinates in different municipalities. Standard-errors in parenthesis and relative effects are in bold for those significant at the 1% level.

Table 11: Migration decisions of members of agricultural producer households in CadÚnico between 2015 and 2020: Effects of droughts by groups of severe drought events and benefits of the BFP.

Precipitation in SDs for the Growing Season (Nov to Apr)	Moved Out	Within	Between
relocation between t and t+1			
Bolsa Familia * Severe Drought	-0.0028	-0.0031	0.0002
	(0.0005)	(0.0004)	(0.0002)
Relative Effect (Δ % Mean Dep. Var. given β)	**-4%**	**-5%**	2%
relocation between t and t+2			
Bolsa Familia * Severe Drought	-0.0047	-0.0052	0.0004
	(0.0005)	(0.0005)	(0.0002)
Relative Effect (Δ % Mean Dep. Var. given β)	**-3%**	**-4%**	2%
relocation between t and t+3			
Bolsa Familia * Severe Drought	-0.0102	-0.0103	0.0002
	(0.0005)	(0.0004)	(0.0002)
Relative Effect (Δ % Mean Dep. Var. given β)	**-5%**	**-6%**	1%

Notes: Authors with data from the CadÚnico, DAP/PRONAF, and CHIRPS Precipitation. Precipitation in SDs for the Growing Season (Nov to Apr) at the grid level. OLS panel estimations with fixed effects at the year and individual levels, time-varying controls for individuals, households, municipalities, and places of origin. Coefficient estimated for the effect of being a *Bolsa Família* beneficiary when affected by an severe drought on the probability of migration of individuals in vulnerable agricultural-producer families between 2015 and 2020. The columns stand for "Moved Out": addresses with different geographical coordinates between time periods; "Within": different geographical coordinates within a same municipality; and "Between": different geographical coordinates in different municipalities. Standard-errors in parenthesis and relative effects are in bold for those significant at the 1% level.

tion probabilities, both for inter- and intra-municipality moves, follow the same patterns and magnitudes. This finding suggests that migration is not limited to, nor disproportionately driven by, the principal decision-maker or benefit holder. Rather, it appears to be a shared household strategy—possibly coordinated among members and shaped by joint exposure to environmental and economic stressors.

This result contributes to the broader literature on household migration and adaptation by emphasizing the collective nature of migration decisions in rural, vulnerable contexts. It resonates with models in which migration is treated as a household-level risk diversification strategy (Stark and Levhari, 1982), rather than an individual-level labor market choice. Under this framework, the role of social protection, such as conditional cash transfers, is to ease credit constraints and provide flexibility in how households allocate migration roles across members.

In this sense, the *Bolsa Família* Program may support mobility not only by enabling a single decision-maker to migrate, but by providing the household with the resources to distribute migration responses among its members based on labor needs, caregiving responsibilities, or social ties. This interpretation underscores the importance of considering intra-household dynamics when evaluating the adaptation effects of social policy.

Table 12: Migration decisions of the main benefit holders members of agricultural producer households in CadÚnico between 2015 and 2020: Effects of droughts by groups of extreme drought events and benefits of the BFP.

Precipitation in SDs for the Growing Season (Nov to Apr)	Moved Out	Within	Between
relocation between t and t+1			
Bolsa Familia * Extreme Drought	0.0056	0.0039	0.0018
	(0.0013)	(0.0012)	(0.0006)
Relative Effect (Δ % Mean Dep. Var. given β)	**9%**	**7%**	**18%**
relocation between t and t+2			
Bolsa Familia * Extreme Drought	0.0069	0.0037	0.0033
	(0.0014)	(0.0013)	(0.0006)
Relative Effect (Δ % Mean Dep. Var. given β)	**6%**	**3%**	**16%**
relocation between t and t+3			
Bolsa Familia * Extreme Drought	0.0025	-0.0002	0.0029
	(0.0012)	(0.0011)	(0.0005)
Relative Effect (Δ % Mean Dep. Var. given β)	1%	0%	**10%**

Notes: Authors with data from the CadÚnico, DAP/PRONAF, and CHIRPS Precipitation. Precipitation in SDs for the Growing Season (Nov to Apr) at the grid level. OLS panel estimations with fixed effects at the year and individual levels, time-varying controls for individuals, households, municipalities, and places of origin. Coefficient estimated for the effect of being a *Bolsa Família* beneficiary when affected by an extreme drought on the probability of migration of individuals in vulnerable agricultural-producer families between 2015 and 2020. The columns stand for "Moved Out": addresses with different geographical coordinates between time periods; "Within": different geographical coordinates within a same municipality; and "Between": different geographical coordinates in different municipalities. Standard-errors in parenthesis and relative effects are in bold for those significant at the 1% level.

Table 13: Migration decisions of the main benefit holders members of agricultural producer households in CadÚnico between 2015 and 2020: Effects of droughts by groups of severe drought events and benefits of the BFP.

Precipitation in SDs for the Growing Season (Nov to Apr)	Moved Out	Within	Between
relocation between t and t+1			
Bolsa Familia * Severe Drought	-0.0017	-0.0021	0.0002
	(0.0006)	(0.0005)	(0.0002)
Relative Effect (Δ % Mean Dep. Var. given β)	**-3%**	**-4%**	2%
relocation between t and t+2			
Bolsa Familia * Severe Drought	-0.0053	-0.0057	0.0002
	(0.0006)	(0.0006)	(0.0003)
Relative Effect (Δ % Mean Dep. Var. given β)	**-4%**	**-5%**	1%
relocation between t and t+3			
Bolsa Familia * Severe Drought	-0.0110	-0.0111	0.0002
	(0.0006)	(0.0006)	(0.0002)
Relative Effect (Δ % Mean Dep. Var. given β)	**-6%**	**-7%**	1%

Notes: Authors with data from the CadÚnico, DAP/PRONAF, and CHIRPS Precipitation. Precipitation in SDs for the Growing Season (Nov to Apr) at the grid level. OLS panel estimations with fixed effects at the year and individual levels, time-varying controls for individuals, households, municipalities, and places of origin. Coefficient estimated for the effect of being a *Bolsa Família* beneficiary when affected by an severe drought on the probability of migration of individuals in vulnerable agricultural-producer families between 2015 and 2020. The columns stand for "Moved Out": addresses with different geographical coordinates between time periods; "Within": different geographical coordinates within a same municipality; and "Between": different geographical coordinates in different municipalities. Standard-errors in parenthesis and relative effects are in bold for those significant at the 1% level.