Pontifícia Universidade Católica
do Rio de Janeiro

Roberta Souza Costa Olivieri

Internal migration and economic shocks: Evidence from droughts in semiarid Brazil

Dissertação de Mestrado

Dissertation presented to the Programa de Pós–graduação em Economia da PUC-Rio in partial fulfillment of the requirements for the degree of Mestre em Economia.

Advisor : Prof. Juliano Junqueira Assunção
Co-advisor: Prof. Gustavo Maurício Gonzaga

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Abstract

Souza Costa Olivieri, Roberta; Assunção, Juliano (Advisor); Gonzaga, Gustavo (Co-Advisor). **Internal migration and economic shocks: Evidence from droughts in semiarid Brazil**. Rio de Janeiro, 2020. 50p. Dissertação de mestrado – Departamento de Economia, Pontifícia Universidade Católica do Rio de Janeiro.

This article studies out-migration responses from Brazilian semiarid population following drought shocks. Migration acts as a coping strategy in poor and rural places as weather shocks exacerbate limited credit and liquidity availability. To find evidence of those mechanisms we compute migration rates at the municipality level starting in 1975 until 2010 using official Census data. Results show that migration rates from the semiarid rise following a drought, especially in the 70s and 80s. Furthermore, we investigate if mobility responses are less pronounced in municipalities where: (i) a larger share of its citizens is eligible to receive rural social security benefits, (ii) have an extended network of bank branches or (iii) built more drought mitigation infrastructure projects.

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Keywords

Internal migration; Natural disasters; Drought shocks; Semiarid Brazil;

Resumo

Souza Costa Olivieri, Roberta; Assunção, Juliano; Gonzaga, Gustavo. **Migração interna e choques econômicos: Evidências de secas no semiárido brasileiro**. Rio de Janeiro, 2020. 50p. Dissertação de Mestrado – Departamento de Economia, Pontifícia Universidade Católica do Rio de Janeiro.

Este artigo estuda as respostas de emigração da população semiárida brasileira após choques de seca. Migração age como uma estratégia de mitigação em locais pobres e rurais, pois os choques climáticos exacerbam a disponibilidade limitada de crédito e liquidez. Para encontrar evidências desses mecanismos, calculamos as taxas de migração ao nível do município entre 1975 e 2010 usando dados oficiais do Censo. Os resultados mostram que as taxas de migração do semiárido aumentam após uma seca, especialmente nas décadas de 70 e 80. Além disso, investigamos se as respostas de mobilidade são menos pronunciadas nos municípios onde: (i) uma parcela maior de seus cidadãos é elegível para receber benefícios rurais de seguridade social, (ii) possui uma rede mais extensa de agências bancárias ou (iii) constrói mais projetos de infraestrutura que visam mitigar o impacto da seca.

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Palavras-chave

Migração interna; Desastres naturais; Choques de seca; Semiárido brasileiro;

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(...)

Sem chuva na terra
Descamba janeiro
Depois fevereiro é o mesmo verão
Entonce o nortista, pensando consigo
Diz: isso é castigo
Não chove mais não

Apela pra março, que é o mês preferido
Do Santo querido, sinhô São José
Mas nada de chuva, tá tudo sem jeito
Lhe foge do peito o resto da fé

Agora pensando, ele segue outra tria
Chamando a famia, começa a dizer
Eu vendo meu burro meu jegue e o cavalo
Nóis vamo a São Paulo viver ou morrê

(...)

Patativa do Assaré & Luiz Gonzaga, *Triste Partida, 1965.*

1
Introduction

Can migration act as a tool to cope with local adverse shocks? The main motivation of the present paper is to investigate if and under what conditions do people move following negative shocks, analyzing the internal migration response of Brazilian semiarid after drought events. For millions of households, especially poorer ones, alternative coping strategies such as credit and liquidity may be constrained, motivating the migration choice. In this framework, weather-related shocks are a relevant example of negative disturbance, with the growing climate change discussion even questioning the possibility of numerous "environmental refugees" in the future (Warner et al. 2009, Tol 2006).

Yet, there is no clear consensus in the literature whether natural disasters indeed increase mobility, and recent studies argue that the relationship is more complex than commonly assumed (Gray and Mueller 2012a, Gray and Mueller 2012b). A negative income shock reduce the opportunity cost of moving, however migration is costly and can actually diminish in underdeveloped regions when income drops. Moreover, easing liquidity constraints may decrease the out-migration response – since there are more alternative ways to cope with the negative shock – but, in a positive income disturbance scenario, it can help to finance the move, actually stimulating migration (Bazzi 2017).

Semiarid Brazil is an appropriate setting to exploit this debate, since it is the poorest region of the country and is geographically vulnerable to water scarcity: Rocha and Soares (2015) found that drought shocks in the area have a negative effect on infant health, influencing birth weight and mortality, and Branco and Féres (2018) found an adverse impact on education due to an increase in child labor. The region is also the most populous semiarid region in the world (Ab'Sáber 1999) and is historically associated with large flows of internal migration (Fusco and Ojima 2015). In this study, our sample of semiarid Brazil includes 920 different municipalities.

Meteorological data comes from official ground-stations and drought is defined considering precipitation and evaporation measures. This approach is more refined than the prevailing one in literature, which uses only rainfall variation to characterize drought, disregarding humidity conditions (Rocha

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and Soares 2015, Branco and Féres 2018, Bastos et al. 2013). Migration data is constructed retrospectively from four official decennial Census, starting in 1980 until 2010, resulting in a municipality-year level panel covering 1975-91 and 1996-2010.

We then apply a two-way fixed effect (FE) model to estimate the impact of drought shocks. This methodology is the most commonly used in climate literature for panel data (Dell et al. 2009), with time and municipality fixed effects. The model accounts for time-invariant municipality-level conditions and for common trends that affect all the semiarid-Brazil region.

Our findings first show that drought shocks affect agricultural output, corroborating the negative impact on the economy. In a year of water scarcity production falls by 3-7%. Second, migration indeed seems to react positively. A drought shock leads to a rise in the migration rate of around 6-7%, including lagged effects up to two previous years. Results stand for three different specifications that alter the drought occurrence's measure and when controlling for temperature. Our heterogeneity analysis implies that color and age do not alter significantly the magnitude of the response and that men are slightly more responsive than women. Furthermore, the out-migration after drought comes primarily from the 70s and the 80s, with no significant response in the 90s and 2010s.

We proceed to investigate three potential mechanisms that could alleviate migration's role as a coping strategy: the rural social security benefit, bank branches *per capita*, and infrastructure projects that mitigate water scarcity in the semiarid (mainly water dams). In the latter case, we also study the effect on agricultural output, believing the channel for lesser mobility is milder economic disruption. Regarding bank branches, we believe they differentiate municipalities by credit availability. Finally, the first mechanism of rural social security distinguishes by local liquidity and is a very relevant government transfer in our framework. Indeed, Assunção and Chein (2009) show that the 1991 reform which increased the coverage and amount of the rural social benefit reduced substantially rural poverty. Additionally, Maranhão and Vieira Filho (2018) present that half of the total spent goes to the Northeast region (where geographically is semiarid Brazil) and explains that although designed to be a retribution payment from rural work, in reality, rural social security acts as an anti-poverty transfer.

Our results reveal that migration after droughts is less pronounced in municipalities where a larger share of its citizens is eligible to receive rural social security benefits in extreme drought events. Hence, local liquidity seems to affect the out-migration response negatively in this setting. Nevertheless, we

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do not find concrete evidence of migration reacting differently in municipalities with more or fewer bank branches (and thus with different degrees of credit availability). For infrastructure projects, results imply that it is very relevant in offsetting the negative impact on agricultural output, but does not impact the out-migration response; the data restriction for projects only after the 90s where mobility is already not responsive may explain the zero estimates. Overall, findings are consistent with migration serving as a coping alternative for negative shocks in the semiarid Brazil framework. Yet, it appears to be a complex relationship and alternative channels beyond the scope of this study might play a role, motivating refinement in further research.

This article is structured as it follows. Section 2 reviews briefly the literature. Section 3 provides a description of the data used. Section 4 explains the methodology of the empirical strategy and its concerns. Section 5 presents the first results and section 6 analyze the mechanisms. Section 7 concludes.

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2
Literature

Weather variability is often used in literature as an exogenous negative productivity shock, especially for agricultural output (Schlenker and Lobell 2010, Feng et al. 2010, Hidalgo et al. 2010). These negative shocks can be pervasive for some households. Jayachandran (2006) shows that for individuals in districts in India who are poorer, more credit-constrained or less able to migrate, adverse conditions are exacerbated. Beegle et al. (2008), for Tanzania, find that crop shocks increase child labor and that asset holdings availability mitigate the negative impact. They mention that in a moral hazard situation this behavior may be due to credit limitations.

Since negative productivity disturbances are not always perfectly absorbed, migration can be an attractive choice. Literature studies migration (and remittances from destination) as a coping strategy in response to weather-related shocks (Gröger and Zylberberg 2016, Yang and Choi 2007). However, there are mixed results in literature for the out-migration response in developing countries following income shocks. Mobility is not only costly and selective, but also the marginal productivity of labor can rise depending on the natural disaster. Another possibility is local adaptive capacity, meaning economies are not severely hurt with weather shocks as they once were.

Tse (2012) argues that earthquakes, volcanic and floods reduced migration in Indonesia; in the case of earthquakes, the reason is the destruction of resources that would potentially finance a move, and for eruptions, lava ash raised the value of farmland. Gray and Mueller (2012b) refine the debate, showing that for rural Bangladesh, flooding has a modest effect on mobility and drought have a positive and significant impact: they argue that this likely reflects a local adaptation for floods and relatively less for other less common disasters. A short-distance migration response also seems to prevail over a long-distance one. Feng et al. (2010) use state-level data in Mexico and find evidence of a climate-driven reduction in crop yields causing emigration to the US, where a 10% decline rises mobility by 2%. Gray and Mueller (2012a), in a setting similar to this study, find that in rural Ethiopia drought increased by 10% the odds of migration. Yet, they defend the multidimensional nature of the relationship, with larger effects on men from land-poor households and

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with a negative response for women in a marriage-induced migration situation. Bazzi (2017) shows that positive rainfall shocks in rural Indonesia rise mobility flows in less developed landholders and reduce in more developed ones, arguing that wealth heterogeneity is key to shape out-migration response. Moreover, he claims that after gaining liquidity people can use the income to finance migration rather than to mitigate the negative shock.

For Brazil, Bastos et al. (2013) question the effect of drought shocks, including if migration is induced in a period that matches our time frame (1970 to 2010). They find a positive response, with younger cohorts and males moving more. Also, their results conclude that the local labor market agricultural sector is deteriorated and that negative spillovers occur to services and manufacturing. However, their analysis is limited to a ten-year panel at the municipality level, whereas in the present study we focus on a municipality-year level panel. Furthermore, it does not answer the role of potential mechanisms that could influence the migration reaction in Brazil after the economic disruption of droughts. The principal contribution of the present study is to find evidence, exploiting municipality heterogeneity, under what local conditions mobility is diminished (or not) after the negative shocks and to offer insights into the complexity of the out-migration response.

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3
Data

3.1
Migration of Semiarid Brazil

Migration data comes from four official Brazilian Census of IBGE (Brazilian Census Bureau): 1980, 1991, 2000 and 2010. Considered as migrants are those who were not born in the municipality they currently live in. If that is the case, the individual also answers how many years he has lived in the current destination (up to 10 years), and, most importantly, the municipality he lived before. Migration information is then constructed retrospectively. An exception is the 2000 Census, where the municipality of origin information only covers the five previous years. Consequently, there is a gap in the database: out-migration panel data at the municipality-year level covers the years 1975-1991 and 1996-2010.

Analysis conducted is of out-migration rate (per 100,000 inhabitants), considering the population of the previous Census, and restricting to migrants between 18 and 55 years old and from the municipalities of *semiarid Brazil*. The subsample of semiarid Brazil is an official classification by Brazilian Ministry of National Integration following three climate criteria[1]. Semiarid-Brazil region today corresponds to 1,262 municipalities, 23% of the total, and to 14%-16% of the Brazilian population in the period of analysis. It must be noted that because the study embraces information since the 70s, data is aggregated to boundaries of 1970, restricting to 920 different semiarid-Brazil municipalities. Migration between municipalities that were merged in 1970 are excluded, otherwise recent flows would be overestimated.

The map in Figure 3.1, item (a), highlights semiarid Brazil. It expands over 9 different states, all of the Northeast region, with the exception of the state of Maranhão and the inclusion of the northern part of Minas Gerais state of the Southeast region. Table 3.1 presents statistics of out-migration and population for the 920 municipalities in the four different decades of analysis. The mean migration rate is around 900 and decreased slightly over time. On

[1]Criteria for a municipality from 1961-90: (i) average yearly precipitation below 800mm, (ii) average Thornthwaite index > 0.5, an index combining humidity and aridity, and (iii) share of days under hydric deficit above 60%.

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the other hand, the mean population of semiarid-Brazil rose, from around 18 thousand in the 70s to 30 thousand in the 2000s.

3.2 Droughts

Earlier studies, including for Brazil framework, use rainfall variation as an indication of drought (Rocha and Soares 2015, Bastos et al. 2013, Hidalgo et al. 2010). However, relying only on precipitation ignore soil, groundwater and vegetation characteristics. Rainfall variation can be misleading since there are humid places that tolerate less rain without the shortage implicating in water scarcity. Therefore, we use an indicator similar to the ones in hydrology studies (Wolfe 1997), the *Aridity Index*, defined as a fraction of accumulated months of evaporation per accumulated months of precipitation (for municipality i and year t):

$$AI_{t,i} = \frac{\sum_{m=1}^{12} \text{ Evaporation}_{m,i,t}}{\sum_{m=1}^{12} \text{ Precipitation}_{m,i,t}} \tag{3-1}$$

The same discussion and index are also presented in Cavalcanti (2018), who shows that in Brazil context the Aridity Index is better suited to account for water balance. Nevertheless, figure A.1 shows that the Aridity Index is highly correlated with the standard rainfall deviation measure, replicated here as Rocha and Soares (2015). In this article, monthly data derive from meteorological ground stations of INMET, Brazil Institute of Meteorology. In INMET case, stations are active since the 1960s and every month precipitation is measured via a pluviograph and evaporation via a Piche evaporimeter. As clearly seen in Figure 3.1, item (b), ground stations are representative in semiarid Brazil, with 75 different stations only in the region.

Weather information is then extrapolated to the municipality level. First, using the municipality's centroid, the closest ground station in each quadrant (northeast, northwest, southwest and southeast) is identified. Then, the inverse square of the distance of centroid and station is used as a weight to calculate the precipitation and evaporation measure, resulting in an Aridity Index for each one of the 920 municipalities. For analysis, adapting the classification of Cavalcanti (2018) and Middleton and Thomas (1997), the variable *Drought* takes a value of one if the Aridity Index is higher or equal than 2. In another specification, with intensity categories of *Drought*, the variable *Extreme* indicates if the index is higher or equal than 5, and *Regular* if is higher or equal than 2 but lower than 5. Equations below resume the classification.

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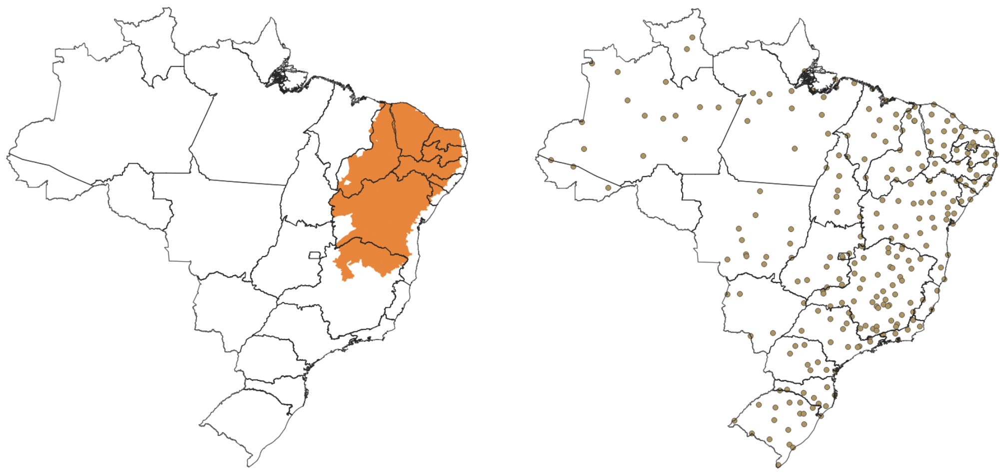
Figure 3.1: **Maps of Brazil**



(a) Semiarid Brazil (b) INMET ground stations

Note: Maps of Brazil divided in today states. Item (a) highlights in the municipalities of semiarid-Brazil region, as classified by the Ministry of National Integration. Item (b) shows the 284 different meteorological ground stations of INMET, active since 1961.

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Table 3.1: **Descriptive statistics**

Mean and standard deviation of semiarid-Brazil municipalities

	1975-80	**1982-91**	**1996-2000**	**2001-10**
Migration Rate	1166	883	923	853
per 100,000 inhabitants	(676)	(609)	(475)	(545)
Population	17968	21027	24692	26995
previous Census	(23136)	(31017)	(41756)	(48587)
Rural Population Proportion	0.75	0.69	0.58	0.50
previous Census	(0.15)	(0.17)	(0.18)	(0.18)
Agricultural Production	483	394	165	210
per capita, real	(543)	(597)	(271)	(537)
Agricultural Production	657	606	316	482
by rural population *per capita*, real	(784)	(1034)	(694)	(1524)
Aridity Index	2.60	2.84	3.15	2.50
evaporation per precipitation	(1.74)	(1.96)	(2.15)	(1.36)
Temperature	24.5	25.1	25.2	25.3
degree Celsius	(1.85)	(1.81)	(1.82)	(1.81)
Observations	5,520	9,200	4,600	9,200

Note: Political boundaries of 1970 are considered with 920 different semiarid Brazil municipalities. Agricultural production is on real *per capita* terms of 2000's Brazilian Real prices. Source of migration and population data are the five decennial Census of 1970-2010. Migrants are between 18 and 55 years old. Source of metereological data is INMET.

$$\textbf{Drought} = \textbf{1} \text{ if Aridity Index } \geq 2.0 \tag{3-2}$$

Intensity categories of *Drought*:

$$\textbf{Regular} = \textbf{1} \text{ if Aridity Index } \geq 2.0 \text{ and } < 5.0 \tag{3-3}$$
$$\textbf{Extreme} = \textbf{1} \text{ if Aridity Index } \geq 5.0 \tag{3-4}$$

Figure 3.2 presents the share of municipalities in semiarid Brazil in every year from 1975-2010 that *Drought* equals one. Famous drought events are recognizable, such as the problematic years of 1979-83 and 1997-99, as well as the "rainy years" of 1985 and 2009 (Marengo et al. 2018). In order to elucidate the cross-section and annual variation, used for identification, maps in Figure 3.3 highlight the municipalities in semiarid Brazil that the Aridity Index took the *Extreme*, *Regular* or no drought ($AI < 2$) interval value for two periods (1975-78 and 1983-86).

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3.3 Municipality Characteristics

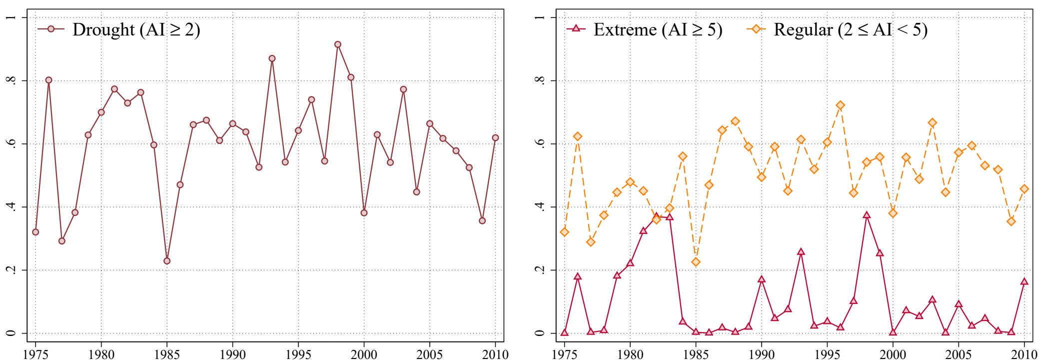
The first empirical exercise is to find evidence that drought shocks have an impact on the local economy. Therefore, we collect data on annual agricultural production *per capita* from the Municipal Agricultural Surveys of IBGE. Table 3.1 contains the mean evolution of the series, showing that agricultural output decreased in real *per capita* terms by half in the latest decades (considering per rural population, the drop was milder, of 27%). Nevertheless, from 1999-2010[2], agriculture accounted for around 17% of the total GDP of semiarid Brazil, in contrast with 5% for all the country.

In a further step, we exploit municipality heterogeneity to analyze some mechanisms that could alleviate the migration choice after drought shocks. The first channel is rural social security, the second is the number of bank branches and the third infrastructure facilities aimed for drought mitigation (mainly water dams). For the rural pension, we estimate a share of citizens eligible to receive the benefit based on official population estimates. The number of bank branches in each municipality comes from the Brazil Central Bank. Infrastructure projects are compiled from official database on central government's transfers to local authorities to finance investments. Section 6 provides a more complete description of data and framework of these mechanisms.

[2]Period when complete GDP data at municipality level are available. Source is IBGE.

Figure 3.2: **Share of municipality occurrence of drought shocks**

Semiarid-Brazil municipalities



Note: Graphs show, for each year from 1975-2010, the share of municipalities in semiarid Brazil with a drought occurrence. Drought events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. AI is the Aridity Index (see text). Source is INMET.

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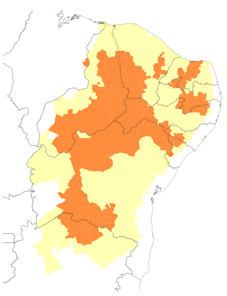
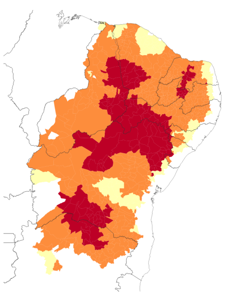
Figure 3.3: **Drought shocks by intensity categories**

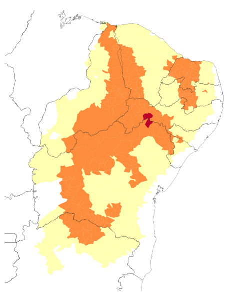
Semiarid-Brazil municipalities



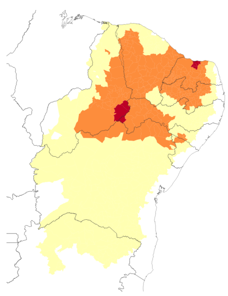
(a) 1975



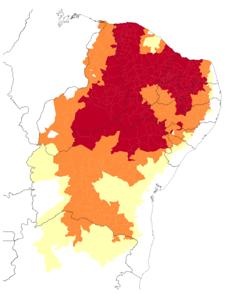
(b) 1976



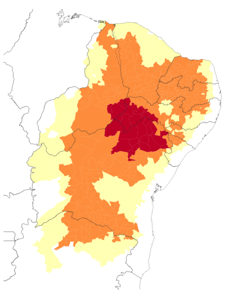
(c) 1977



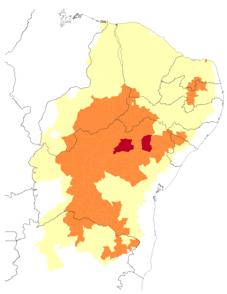
(d) 1978



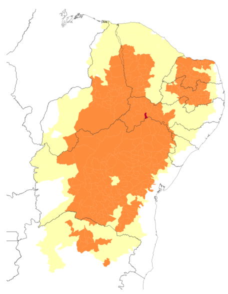
(e) 1983



(f) 1984



(g) 1985



(h) 1986

Note: Semiarid Brazil divided in its 920 municipalities. *Extreme* drought events in red ($AI \geq 5$), *Regular* in orange ($2 \leq AI < 5$) and no drought occurrences in yellow ($AI < 2$). AI is the Aridity Index (see text). Source is INMET.

4
Methodology

The empirical strategy adopted to study the relationship between drought shocks and migration is the two-way fixed effect (FE) model. This model is widely common (Dell et al. 2009), including for panel data exercises analysing weather-related shocks (Hidalgo et al. 2010, Feng et al. 2010, Feng et al. 2015). It includes municipality and year fixed effects. Therefore, the model accounts for: (i) time-invariant municipality-level conditions, such as soil quality and distance from urban capitals, and (ii) factors that affect all the semiarid-Brazil region, such as job market attractiveness in emigration destinations like Brasília and the Southeast. For identification, we assume without much concern that weather events happen independently of individuals' actions.

The study uses three different specifications, varying the drought shock's measure:

$$\ln y_{i,t} = \alpha + \boldsymbol{\beta_1}\mathbf{Drought}_{i,t^*} + \delta T_{i,t^*} + \gamma_i + \theta_t + \epsilon_{i,t} \tag{4-1}$$

$$\ln y_{i,t} = \alpha + \boldsymbol{\beta_2}\mathbf{Aridity}_{i,t^*} + \delta T_{i,t^*} + \gamma_i + \theta_t + \epsilon_{i,t} \tag{4-2}$$

$$\ln y_{i,t} = \alpha + \boldsymbol{\beta_3}\mathbf{Extreme}_{i,t^*} + \boldsymbol{\beta_4}\mathbf{Regular}_{i,t^*} + \delta T_{i,t^*} + \gamma_i + \theta_t + \epsilon_{i,t} \tag{4-3}$$

Where $\epsilon_{i,t}$ is the error term, i indexes municipality and t year. We first question whether drought shocks affect output, with $y_{i,t}$ = real agricultural production *per capita*. Later we investigate out-migration, with $y_{i,t}$ = migration rate, and considering lagged effects up to two previous years. In equation 4-1, treatment is the *Drought* event dummy, in equation 4-2 is the continuous variable of *Aridity Index*, and in equation 4-3 is the two indicator variables for intensity categories of drought, *Extreme* and *Regular*, all defined in previous section 3. $\boldsymbol{\beta}$ is the coefficient of interest. This structure is repeated in every analysis. Regressions also control for local temperature – T_{i,t^*} – since its value can also influence the local economy productivity (Dell et al. 2009) and it correlates with evaporation and precipitation levels. Controlling for temperature enforces that we are measuring a clearer effect of water scarcity and not of warmer weather (Rocha and Soares 2015).

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For the mechanisms exercise, the question is whether revenue from a non-labor income (rural social security), credit availability (number of bank branches) and drought mitigation policies (infrastructure projects) alter the drought impact on out-migration. We run regressions of the following equations, using interactions:

$$\ln m_{i,t} = \alpha + \beta(\text{Drought Measure})_{i,t^*} + \boldsymbol{\rho} X_{i,t^*} \times (\text{Drought Measure})_{i,t^*} + \psi X_{i,t^*} + \delta T_{i,t^*} + \gamma_i + \theta_t + \epsilon_{i,t} \quad (4\text{-}4)$$

Where $m_{i,t}$ = is the migration rate, $X_{i,t}$ is the mechanism of analysis variable, $\boldsymbol{\rho}$ the coefficient of interest, and (Drought Measure) alters between the three drought specifications of equations 4-1, 4-2 and 4-3 above.

Recently, econometric literature has been questioning the two-way FE model. Goodman-Bacon (2018) and Chaisemartin and D'Haultfoeuille (2019) explain that the two-way FE coefficient, when expanding to a $n \times n$ setup, correspond to a weighted average of several simple 2×2 difference-in-difference estimators. Weights sum to one but may be negative and this can be a concern when the treatment effect is heterogeneous across groups or over time. To overcome this potential issue, some studies suggest alternative estimators, however literature on this topic is still very recent and scarce. Abraham and Sun (2018) and Goodman-Bacon (2018) only provide estimators in a staggered adoption setting. Chaisemartin and D'Haultfoeuille (2019) present a slightly more general case, but under an assumption of treatment monotonicity, where treatment status is stochastically increasing within a group. Our setup is more general, as we allow for treatment adoption at different points in time and reversal to the control condition. As a result, an econometric refinement and robustness checks in this study dealing with this issue are still missing.

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5
Results

5.1
Agricultural Production

First, we look for empirical evidence that drought is a negative productivity shock for municipalities in semiarid Brazil. Our dependent variable is the municipal agricultural production *per capita*. Results are in table 5.1 with each specification in columns.

Estimates imply that droughts shocks affect significantly the economy. Coefficients are negative and statistically significant and show that agricultural output decreased by 3%-7% in a water scarcity year. This result match Hidalgo et al. (2010) and Bastos et al. (2013), who also studies drought and agricultural output in Brazil. Furthermore, it is clear the disruptive effect of a *Extreme* drought scenario: output, on average, falls by 33%, ten times worse then a *Regular* event. A table

5.2
Migration

After corroborating the negative impact of a drought shock in semiarid Brazil, we now investigate if people migrate as a response. The dependent variable is the municipality migration rate. Estimates are in table 5.2 and the functional form considers that drought up to two years before can affect mobility.

Results show that indeed people migrate because of a drought event. Coefficients are positive and statistically significant and stand for the three specifications and when controlling for annual temperature. A drought event in the present year increases the migration rate by 6-7%, and by 3-4% in previous years. This magnitude is similar to Gray and Mueller (2012a) and Bastos et al. (2013). Also, *Extreme* drought events lead to a higher out-migration than *Regular* ones, although when controlling for temperature point estimates and statistical significance decrease. Nevertheless, it seems that in the semiarid-Brazil case, local municipalities are not fully adapted to weather shocks and migration acts as a coping strategy.

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Table 5.1: **Drought shocks impact on agricultural output**
Semiarid-Brazil municipalities (1975-91; 1996-2010)

	Dependent variable: ln(**Real Agricultural Output**)					
	(1)	(2)	(3)	(4)	(5)	(6)
A.						
Drought	-0.0331**	-0.0220				
	(0.0154)	(0.0158)				
B.						
Aridity Index			-0.0672***	-0.0683***		
			(0.0049)	(0.0051)		
C.						
Drought Intensity:						
Extreme					-0.3308***	-0.3232***
					(0.0290)	(0.0300)
Regular					-0.0354**	-0.0323**
					(0.0156)	(0.0160)
Temperature		-0.0297**		0.0067		-0.0082
		(0.0117)		(0.0120)		(0.0120)
Municipality FE	X	X	X	X	X	X
Year FE	X	X	X	X	X	X
Observations	28,520	28,520	28,520	28,520	28,520	28,520
Adjusted R^2	0.616	0.616	0.621	0.621	0.620	0.620

Note: Robust standard error clustered at municipality level in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Agricultural production is on real *per capita* terms of 2000's Brazilian Real prices. Drought events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. *AI* is the Aridity Index (see text). Sources are Census, IBGE and INMET.

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Table 5.2: **Drought shocks impact on migration**
Semiarid-Brazil municipalities (1975-91; 1996-2010)

	Dependent variable: ln(**Migration Rate**)						
	(1)	(2)	(3)	(4)		(5)	(6)
A.					*C.*		
Drought	0.0706***	0.0641***			**Extreme**	0.0764***	0.0604**
	(0.0147)	(0.0151)				(0.0276)	(0.0292)
Drought(-1)	0.0256**	0.0204			**Regular**	0.0696***	0.0632***
	(0.0128)	(0.0132)				(0.0148)	(0.0152)
Drought(-2)	0.0397***	0.0375***			**Extreme(-1)**	0.0654**	0.0526
	(0.0143)	(0.0144)				(0.0302)	(0.0322)
B.					**Regular(-1)**	0.0262**	0.0220*
Aridity Index			0.0134***	0.0101**		(0.0129)	(0.0133)
			(0.0043)	(0.0047)	**Extreme(-2)**	0.0424	0.0390
Aridity Index(-1)			0.0084	0.0065		(0.0334)	(0.0341)
			(0.0058)	(0.0063)	**Regular(-2)**	0.0378***	0.0363**
Aridity Index(-2)			0.0050	0.0039		(0.0143)	(0.0144)
			(0.0051)	(0.0052)		6.5913***	
						(0.0213)	
Temperature		0.0183		0.0188	Temperature		0.0190
		(0.0127)		(0.0134)			(0.0131)
Temperature(-1)		0.0105		0.0072	Temperature(-1)		0.0076
		(0.0111)		(0.0120)			(0.0116)
Temperature(-2)		0.0043		0.0067	Temperature(-2)		0.0045
		(0.0096)		(0.0097)			(0.0097)
Municipality FE	X	X	X	X		X	X
Year FE	X	X	X	X		X	X
Observations	28,520	28,520	28,520	28,520		28,520	28,520
Adjusted R^2	0.313	0.313	0.313	0.313		0.313	0.313

Note: Robust standard error clustered at municipality level in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Migration rate equals migrants per 100,000 inhabitants of each semiarid-Brazil municipality. Migrants are between 18 and 55 years old. Drought events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. *AI* is the Aridity Index (see text). Sources are Census, IBGE and INMET.

5.2.1
Heterogeneity by color, gender and age

Dividing the migration rate by subgroups we can question if the mobility response differs depending on color, gender, and age. Table A.1 in appendix presents the average migration of each group by decade and table 5.3 contains the regression results. In both tables, the first panel divides between white and non white[1] individuals, the second between men and women and the last between those above and below 37 years old (median value of the age interval criteria for migrants, 18 to 54). From table A.1, crude migration rates are higher than what demographics would imply for white and younger individuals. Between genders, there is no clear difference, with population and migration rates split almost evenly.

But does the migration choice caused by droughts vary by any of these individual characteristics? First panel in table 5.3 imply that color does not make a difference since non white and white people respond to the negative shock with very similar coefficients. For gender, both also react, but men seem to be more responsive marginally. Bastos et al. (2013) find that the mobility reaction is less pronounced in women as well. In the third panel, estimates suggest that both individuals above and below 37 years migrate and with comparable magnitude. However, younger migrants tend to react more to recent drought events whereas older migrants to more ancient ones.

5.2.2
By decade

The analysis in this study incorporates four different decades. Separating the sample in each decade we can investigate if the effect is recent or comes from older periods. From table 5.4, it is clear that the out-migration response after droughts is essentially in the 70s and 80s, with coefficients statistically zero after the 90s.

In the appendix, table A.2 shows that drought still affects the economy in more recent years. Hence, there is no evidence that the diminished out-migration after the 90s is explained by a scenario where drought shocks are less disruptive to the local agricultural output. We study the role of mechanisms behind out-migration in section 6, and the expansion of rural social security in 1991, for example, can explain partly this phenomenon. In the final section 7, we mention more channels that are beyond the scope of this study, such as social welfare programs.

[1]Following IBGE classification, non white includes black, mixed ("*pardo*") and Asian.

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Table 5.3: **Drought shocks impact on migration**

Semiarid-Brazil municipalities (1975-91; 1996-2010)

	Dependent variable: ln(**Migration Rate**)						
I. Color:	(1) **Non White**	(2) **White**	(3) **Non White**	(4) **White**		(5) **Non White**	(6) **White**
A.					*C.*		
Drought	0.0710***	0.0756***			**Extreme**	0.0625	0.0975**
	(0.0187)	(0.0269)				(0.0383)	(0.0458)
Drought(-1)	0.0443**	0.0390			**Regular**	0.0695***	0.0758***
	(0.0187)	(0.0264)				(0.0188)	(0.0271)
Drought(-2)	0.0438**	0.0500*			**Extreme(-1)**	0.0939**	0.0654
	(0.0222)	(0.0264)				(0.0441)	(0.0503)
B.					**Regular(-1)**	0.0483**	0.0379
Aridity			0.0124*	0.0178**		(0.0189)	(0.0265)
			(0.0068)	(0.0086)	**Extreme(-2)**	-0.0104	0.1057*
Aridity(-1)			0.0126	0.0021		(0.0435)	(0.0562)
			(0.0079)	(0.0093)	**Regular(-2)**	0.0399*	0.0504*
Aridity(-2)			-0.0020	0.0153		(0.0223)	(0.0266)
			(0.0070)	(0.0100)			
Observations	28,520	28,520	28,520	28,520		28,520	28,520
Adjusted R^2	0.295	0.287	0.295	0.287		0.295	0.287
II. Gender:	(7) **Female**	(8) **Male**	(9) **Female**	(10) **Male**		(11) **Female**	(12) **Male**
A.					*C.*		
Drought	0.0678***	0.0781***			**Extreme**	0.0923**	0.0911**
	(0.0188)	(0.0204)				(0.0361)	(0.0385)
Drought(-1)	0.0074	0.0369*			**Regular**	0.0674***	0.0790***
	(0.0187)	(0.0188)				(0.0189)	(0.0205)
Drought(-2)	0.0276	0.0636***			**Extreme(-1)**	0.0674	0.0187
	(0.0198)	(0.0194)				(0.0416)	(0.0418)
B.					**Regular(-1)**	0.0090	0.0347*
Aridity			0.0168***	0.0223***		(0.0188)	(0.0189)
			(0.0063)	(0.0071)	**Extreme(-2)**	0.0342	0.0959**
Aridity(-1)			0.0088	0.0025		(0.0451)	(0.0423)
			(0.0074)	(0.0079)	**Regular(-2)**	0.0247	0.0652***
Aridity(-2)			0.0058	0.0025		(0.0200)	(0.0195)
			(0.0072)	(0.0073)		0.0128	0.0178
Observations	28,520	28,520	28,520	28,520		28,520	28,520
Adjusted R^2	0.249	0.271	0.249	0.271		0.249	0.271
III. Age:	(13) **Young (< 37)**	(14) **Old (≥ 37)**	(15) **Young (< 37)**	(16) **Old (≥ 37)**		(17) **Young (< 37)**	(18) **Old (≥ 37)**
A.					*C.*		
Drought	0.0725***	0.0195			**Extreme**	0.0624*	0.0248
	(0.0171)	(0.0299)				(0.0325)	(0.0559)
Drought(-1)	0.0353**	0.0606**			**Regular**	0.0717***	0.0191
	(0.0149)	(0.0302)				(0.0171)	(0.0298)
Drought(-2)	0.0195	0.0820**			**Extreme(-1)**	0.0543	0.0850
	(0.0157)	(0.0318)				(0.0362)	(0.0584)
B.					**Regular(-1)**	0.0364**	0.0603**
Aridity			0.0064	0.0172		(0.0151)	(0.0304)
			(0.0058)	(0.0110)	**Extreme(-2)**	0.0278	0.1293**
Aridity(-1)			0.0045	0.0198*		(0.0387)	(0.0609)
			(0.0070)	(0.0105)	**Regular(-2)**	0.0193	0.0826**
Aridity(-2)			0.0001	0.0076		(0.0157)	(0.0320)
			(0.0064)	(0.0102)			
Observations	28,520	28,520	28,520	28,520		28,520	28,520
Adjusted R^2	0.291	0.240	0.290	0.240		0.291	0.240
Control (Temp)	X	X	X	X		X	X
Municipality FE	X	X	X	X		X	X
Year FE	X	X	X	X		X	X

Note: Robust standard error clustered at municipality level in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Migration rate equals migrants per 100,000 inhabitants of each semiarid-Brazil municipality. Migrants are between 18 and 55 years old; the third panel (*III. Age*) considers 37 years of age as the threshold for young and old. Non-white in the first panel (*I. Color*) includes black, mixed ("*pardo*") and Asian races. *Drought* events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. *AI* is the Aridity Index (see text). Sources are Census, IBGE and INMET.

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Table 5.4: **Drought shocks impact on migration**

Semiarid-Brazil municipalities (1975-91; 1996-2010)

	Dependent variable: ln(**Migration Rate**)			
	(1)	(2)	(3)	(4)
	1975-80	**1982-91**	**1996-2000**	**2001-10**
A.				
Drought	0.0689***	0.0653**	0.0667*	0.0169
	(0.0202)	(0.0327)	(0.0351)	(0.0281)
Drought(-1)	0.0705***	0.0170	0.0262	-0.0231
	(0.0194)	(0.0297)	(0.0415)	(0.0280)
Drought(-2)	0.0439**	0.0864***	-0.0056	0.0088
	(0.0204)	(0.0317)	(0.0393)	(0.0284)
Control (Temp)	X	X	X	X
Munic FE	X	X	X	X
Year FE	X	X	X	X
Observations	5,520	9,200	4,600	9,200
Adjusted R^2	0.556	0.337	0.325	0.341
	(5)	(6)	(7)	(8)
B.				
Aridity Index	0.0308***	0.0063	0.0112	-0.0203*
	(0.0075)	(0.0116)	(0.0108)	(0.0120)
Aridity Index(-1)	0.0082	-0.0002	-0.0020	-0.0067
	(0.0064)	(0.0120)	(0.0098)	(0.0133)
Aridity Index(-2)	0.0097	0.0137	0.0178	-0.0174
	(0.0077)	(0.0088)	(0.0138)	(0.0125)
Control (Temp)	X	X	X	X
Municipality FE	X	X	X	X
Year FE	X	X	X	X
Observations	5,520	9,200	4,600	9,200
Adjusted R^2	0.555	0.336	0.325	0.341
	(9)	(10)	(11)	(12)
C.				
Extreme	0.1238***	0.0482	0.0478	-0.0745
	(0.0371)	(0.0691)	(0.0672)	(0.0612)
Regular	0.0731***	0.0655**	0.0640*	0.0147
	(0.0206)	(0.0326)	(0.0357)	(0.0281)
Extreme(-1)	0.0439	0.0303	0.0208	0.0050
	(0.0347)	(0.0675)	(0.0697)	(0.0619)
Regular(-1)	0.0589***	0.0159	0.0263	-0.0208
	(0.0201)	(0.0299)	(0.0421)	(0.0281)
Extreme(-2)	0.0789*	0.1184**	-0.0033	-0.0285
	(0.0452)	(0.0603)	(0.0724)	(0.0619)
Regular(-2)	0.0420*	0.0864***	-0.0052	0.0044
	(0.0221)	(0.0318)	(0.0389)	(0.0278)
Control (Temp)	X	X	X	X
Municipality FE	X	X	X	X
Year FE	X	X	X	X
Observations	5,520	9,200	4,600	9,200
Adjusted R^2	0.556	0.337	0.325	0.341

Note: Robust standard error clustered at municipality level in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Migration rate equals migrants per 100,000 inhabitants of each semiarid-Brazil municipality. Migrants are between 18 and 55 years old. Drought events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. AI is the Aridity Index (see text). Sources are Census, IBGE and INMET.

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6
Mechanisms

6.1
Rural Social Security

The idea behind the rural social security benefit is retribution payment of the government for previous informal rural work. Beneficiaries have to prove they worked in agriculture to receive the pension. The aid was created in 1972 and was firstly equivalent to half the minimum wage, covering the head of households who were above 65 years old. The Ordinary Law of 1991 amplified the benefit in magnitude and coverage: the value increased to 100% the minimum wage and citizens eligible extended to males above 60 years and females above 55 years old. As mentioned, this expansion of rural social security in the 90s was relevant for the rural poverty reduction in Brazil (Assunção and Chein 2009); moreover, the benefit destination is mainly the Northeast (Maranhão and Vieira Filho 2018).

There is no official historical data on the annual number of beneficiaries by municipality. Hence, for analysis, interest is in the *eligible population share for rural social security* at the municipality-year level, presumably a good predictor of actual recipients. Since 1980, IBGE estimates for each year the municipality's population discriminating by age and gender. However, the rate living in the rural area is not available for each year, only at the decennial Census. As a result, we interpolated the proportion between Census years. Then, we construct the variable of interest – an estimation of the rate of citizens eligible – by multiplying the rural area proportion with the share of the population that matches the criteria. A note is that "head of household" for years before 1991 is proxied as men exclusively without much concern[1].

Figure 6.1, items (a)-(b), shows the evolution and municipality's density of the eligible population share estimate for 1980-2010. Clearly, there was a major change after 1991, when the mean share increased from 1% to around 6%. In the appendix, figure A.2 presents the same two statistics for the rural

[1]In 1980, 84% of all households in Brazil were male-headed. For the semiarid-Brazil rural area in the period 1980-91, this proportion is certainly higher: in 2000 (when more discriminated IBGE data is available) 65% of urban households were male-headed, against 85% of rural ones. Sources are Census and PNAD.

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area proportion (also in table 3.1). Population rate living in the countryside in semiarid-Brazil dropped 24% in thirty years, although the 2010 level of 45% is still very high relatively with the rest of the country[2]. To find evidence that our measure of eligible population share is a good instrument for the actual recipients of the rural social security, we look into the Census years of 2000 and 2010 (when beneficiaries' information at the municipality level is available). Scatter plots between both variables display a high correlation, as seen in figure 6.2, items (c)-(d). Additionally, table A.3 in the appendix contains the regression indicating that the municipality's eligibility variable is indeed a good predictor of the share of recipients.

The question of interest is if local liquidity from rural security can affect out-migration reaction to drought shocks. Two important notes of this analysis should be mentioned. First, the rural area population rate is correlated with our eligible share measure (by construction) and it is reasonable to presume that it also influences the drought effect on migration: the more proportionally the municipality's population lives in the countryside the more water scarcity affect it. For that reason, we control for the rural area proportion interaction in regressions. Second, the denominator of the migration rate used here is the municipality population of 18-55 years old. Our dependent variable is then a migration rate "per the young population". As we interact the drought shock with a share of older people, and reasonably migration is reduced for the elderly, this adjustment is necessary to better isolate the impact of interest. Otherwise, mechanically we could have a significant correlation simply because presumably the very old tend to migrate less than the young.

Results for the interaction of drought shocks and the municipality's eligible population share are in table 6.1. To avoid multicollinearity the lagged years treatments are run separately. Overall, coefficients are negative and statistically significant in *Extreme* drought events, indicating that municipalities that receive more rural pension revenue move less. This evidence is consistent with limited liquidity inducing the migration alternative after a negative productivity shock. Moreover, as expected, an increase in the rural area proportion of the municipality enhance the drought effect on mobility. For visualization, figure 6.3 has a quantitative analysis, where each dot corresponds to a municipality and the two interaction coefficients of columns (1) and (5) in table 6.1 are used. Estimates show that drought shocks lead to an increase of 1%-5% of the municipality migration rate, on average, with lower impacts at higher values of eligible population share for rural social security in *Extreme* events.

[2]Brazilian urbanization rate in 2010 is 84%. Source is Census.

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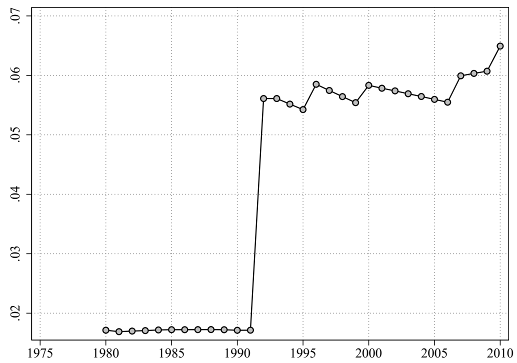
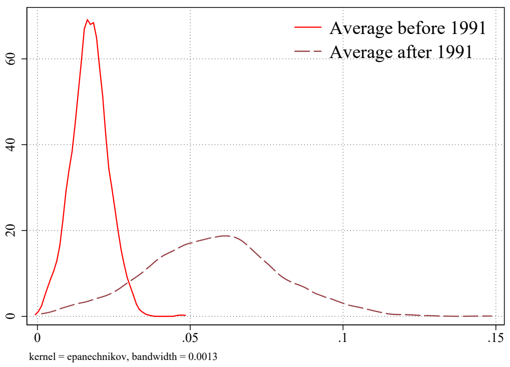
Figure 6.1: **Eligible population share for rural social security in semi-arid Brazil**

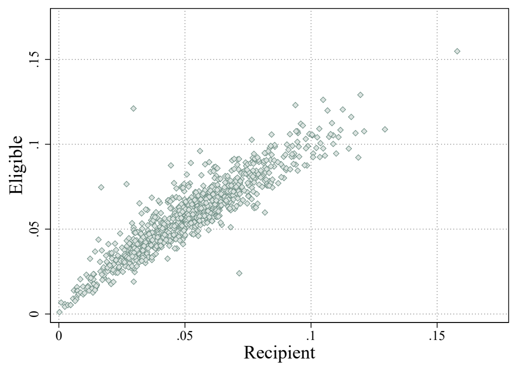


(a) Municipalities' average

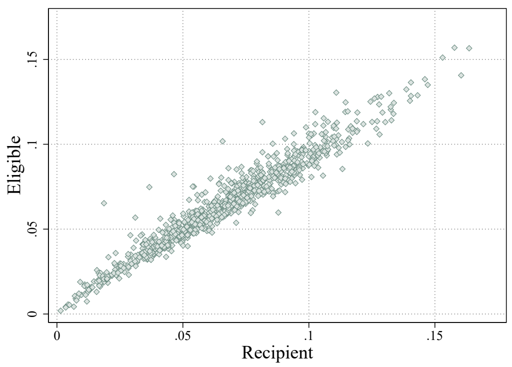


(b) Density: 1980-1991 vs 1992-2010

Figure 6.2: **Recipient and eligible population shares for rural social security in semiarid Brazil**

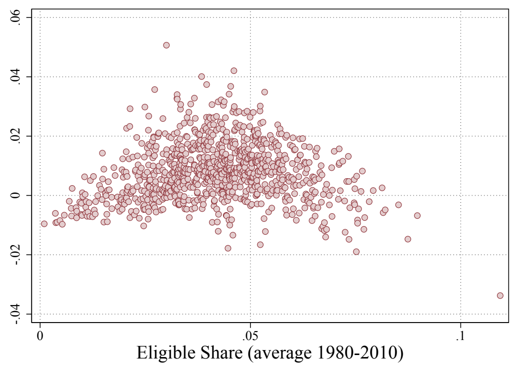


(c) 2000

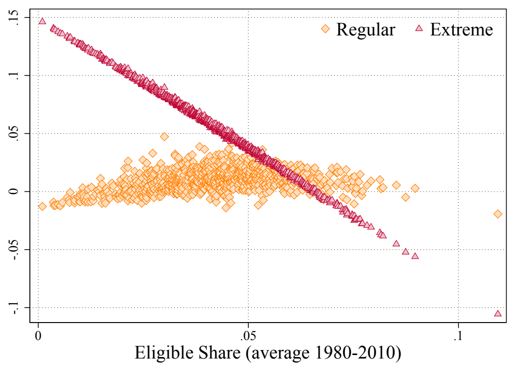


(d) 2010

Figure 6.3: **Drought effect on migration, by the average eligible population share for rural social security in semiarid Brazil**



(e) *Drought* shock



(f) *Extreme* and *Regular* shock

Note: Figure 6.1 presents estimates of eligible population share for rural social security for all 920 municipalities in semiarid Brazil: (a) displays each year average between municipalities and (b) densities of each municipality's average for pooled years. Figure 6.2 (c)-(d) display scatter plots of eligible and recipient population shares at two points in time, 2000 and 2010. In figure 6.3, each dot represent a municipality: (e) uses coefficients of column (1) and (f) of column (5) in Table 6.1 and multiply them by the averages 1980-2010 of the eligible share and rural area proportion. Sources are IBGE and Census.

Table 6.1: **Drought shocks impact on migration**
Semiarid-Brazil municipalities (1980-91; 1996-2010)

	Dependent variable: ln(**Migration Rate**)			
	(1) $t = -1$	(2) $t = -2$	(3) $t = -1$	(4) $t = -2$
A.				
Drought(t)	-0.0111	-0.0202		
	(0.0571)	(0.0618)		
Drought(t)*ES(t)	-1.1213*	-1.2373*		
	(0.6682)	(0.6614)		
Drought(t)*RA(t)	0.1191	0.1857**		
	(0.0908)	(0.0940)		
B.				
Aridity Index(t)			0.0148	0.0014
			(0.0195)	(0.0177)
Aridity(t)*ES(t)			-0.2391	-0.3040
			(0.1836)	(0.1996)
Aridity(t)*RA(t)			0.0073	0.0321
			(0.0295)	(0.0260)
Eligible Share(t)	5.6675***	5.7679***	5.4971***	5.7641***
	(1.2245)	(1.2209)	(1.2038)	(1.2190)
Rural Area(t)	-0.3241	-0.3403	-0.2672	-0.3224
	(0.3449)	(0.3525)	(0.3588)	(0.3657)
Control (Temp)	X	X	X	X
Municipality FE	X	X	X	X
Year FE	X	X	X	X
Observations	23,000	23,000	23,000	23,000
Adjusted R^2	0.334	0.334	0.334	0.334
	(5) $t = -1$	(6) $t = -2$		
C.				
Extreme(t)	0.1482	-0.0178		
	(0.1244)	(0.1200)		
Regular(t)	-0.0144	-0.0148		
	(0.0566)	(0.0611)		
Extreme(t)*ES(t)	-2.4709*	-2.8231**		
	(1.3318)	(1.4331)		
Regular(t)*ES(t)	-0.8933	-1.0077		
	(0.6723)	(0.6545)		
Extreme(t)*RA(t)	0.0196	0.3010*		
	(0.1942)	(0.1809)		
Regular(t)*RA(t)	0.1104	0.1575*		
	(0.0900)	(0.0935)		
Eligible Share(t)	5.5257***	5.7152***		
	(1.2133)	(1.2111)		
Rural Area(t)	-0.3155	-0.3578		
	(0.3464)	(0.3542)		
Control (Temperature)	X	X		
Municipality FE	X	X		
Year FE	X	X		
Observations	23,000	23,000		
Adjusted R^2	0.334	0.334		

Note: Robust standard error clustered at municipality level in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Migration rate equals migrants per 100,000 inhabitants between 18-54 years old of each semiarid-Brazil municipality. ES = Eligible population share for rural social security benefit, based on sex and age criteria and on the rural area proportion of each municipality. RA = Rural area proportion of each municipality. Drought events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. AI is the Aridity Index (see text). Sources are Census, IBGE and INMET.

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6.2
Bank Branches

At first glance, more credit availability should decrease migration response as a coping strategy. We will look for this evidence distinguishing municipalities by their network of bank branches. Data of all branches each year is compiled based on official recordings of Brazil Central Bank and we consider public and private active branches. Total is divided by the population (rate per 100,000 inhabitants).

An important note is that in the semiarid Brazil setting, for most years, a large share of municipalities do not have any bank branch at all. Figure 6.4, item (b), shows that the municipality's density of the number of bank branches averaged in all pooled years (1975-2010) is very close to zero. Item (a) of Figure 6.4 corresponds to the mean evolution and we can also note that the municipality's average was at the maximum equals to 12 branches per 100,000 inhabitants, and for almost all years was below 7.

Table 6.2 contains the results for the interactions of drought shocks and the rate of bank branches. The main conclusion is that, in general, the interaction coefficient is not significantly different from zero. In other words, we do not find any empirical evidence that municipalities in semiarid-Brazil with more bank branches (and therefore credit availability) migrate less due to drought shocks. Coefficient of interactions are negative in some columns and positive in others. Figure 6.4, items (c)-(d), provides a quantitative analysis of the drought effect on migration based on the coefficient of columns (1) and (5). Wide confidence intervals show that we cannot reject that when increasing the x-axis, the number of bank branches, the out-migration after a drought is the same.

6.3
Infrastructure

The last mechanism is infrastructure facilities that can potentially reduce the negative consequence of drought shocks. Brazil's federal government often makes agreements with state and municipality's authorities to transfer resources for projects, the so-called *Convênios*. In that way, public expenditure is decentralized, and long-last policies of drought mitigation mainly come from these *Convênios* agreements (Cavalcanti 2018). Data is provided by the government[3] at the contract level and starts in 1996.

[3]More specifically, the Office of the Comptroller General (CGU), the Brazilian government's branch responsible for transparency policies.

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From all contracts in the semiarid-Brazil region during 1996-2010, we restrict the data to the ones that are finished and could alleviate a drought event, reaching a total of 1,065 projects. They are identified when their description contains certain keywords, for example "*dams*" ("*açude*" or "*barragem*" in Portuguese) or "*technologies for the semiarid*". Figure 6.6 and table A.4 in the appendix present the total number of projects in the 1996-2010 period by state and municipality.

Two important notes of the descriptive data should be mentioned. First, cases seem concentrated in the Ceará state in the northwest part of semiarid-Brazil, as shown in table A.4. Geographically, it makes sense, as the state only has intermittent rivers and groundwater is low and salty. Projects in the state also are mainly conducted by the National Department of Construction Works Against Drought (DNOCS), whose headquarters are in Ceará. DNOCS is an office created in 1909 and it is indeed the main way dams and other infrastructure works are financed in semiarid Brazil – in our data represents a third of all projects. Second, DNOCS is regarded by the federal accountability office (Federal Court of Accounts, TCU) as one of the public offices with the highest risk of corruption (TCU 2018). In the Northeast, there is even the "Industry of Drought" political term, meaning politicians in the semiarid take advantage of the drought vulnerability situation to demand resources from the federal government, but, in the end, use some of the financial aid for their own (or the rural elite) benefit. Some projects can be overpriced for allowing corruption schemes, especially in remote semiarid municipalities. For this reason and because the cost of the project does not necessarily reflect the benefit value for the local population, we use dummies for the infrastructure project variables:

$$X_{i,t} = I(\text{Infrastructure projects Finished} = \boldsymbol{j})_{i,t} = I(\text{IF} = \boldsymbol{j})_{i,t} \tag{6-1}$$

The equation above corresponds to the infrastructure variables for municipality i at year t. To start, $\boldsymbol{j} = \{0, 1, 2, 3\}$, meaning there are four different variables that always sum to one in a year t. When the indicator for $\boldsymbol{j} = 0$ is the one on, municipality i did not finish any drought mitigation project from the beginning of the sample, in 1996, until the specific year t. If the municipality finishes one, for example in 1998, then $I(\text{IF} = \mathbf{1})_{i,1998}$ is the dummy that now takes the value of one. Supposing that this municipality i remains with only this project, then for all the posterior years until 2010: $I(\text{IF} = \mathbf{1})_{i,t\geq 1998} = 1$, when $\boldsymbol{j} = 1$, and $I(\text{IF} = \boldsymbol{j})_{i,t\geq 1998} = 0$ otherwise, when $\boldsymbol{j} = \{0, 2, 3\}$. When $\boldsymbol{j}$ equals its highest value, $\boldsymbol{j} = 3$, three or more projects were finished from 1996 until the year t. Figure 6.7 shows the number of municipalities from the

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total pool of 920 in each category by year. The omitted infrastructure dummy variable in regressions is $I(\text{IF} = \mathbf{0})_{i,t}$.

First, we investigate if infrastructure has an impact on the economic disruption caused by drought shocks. Table 6.3 presents the results with agricultural production as the dependent variable. Coefficients for the interactions are mainly positive and significant for the three models, indicating that the infrastructure projects are effective in reducing the negative influence of drought for economic activity. However, point estimates of the interactions vary and are also very high, implying a scenario where the projects essentially offset the negative impact. Table 6.4 contains the regressions for out-migration. Our findings imply that in the period 1996-2010, overall drought does not affect mobility, the same conclusion from section 5. Moreover, interactions are not significant, meaning there is no evidence that more infrastructure for drought mitigation resulted in lesser out-migration after the shocks, even with the significant impact on agricultural output. Nevertheless, the data restriction can also explain results, since migration does not seem to be relevant as a reaction to drought shocks after the 90s in the first place.

An observation of the analysis is that dams and other infrastructure constructions can affect neighboring municipalities. For that reason, in appendix's tables A.5 and A.6 we consider a scenario where municipalities close to the ones with projects benefited from them as well. The rule applied is at least 20 kilometres between centroids. Since this second structure implies a higher or equal amount of projects for each municipality, $\boldsymbol{j}$ varies into more options: $\boldsymbol{j} = \{0, 1, 2, 3, 4, 5\}$. For example, comparing figures 6.7 and A.3, without spillovers, there are around 560 municipalities that did not have any project in 1996-2010; in the new framework, this number drops to 340. The main takeaway is that overall results and conclusions do not differ comparing to the model without spillovers across municipalities.

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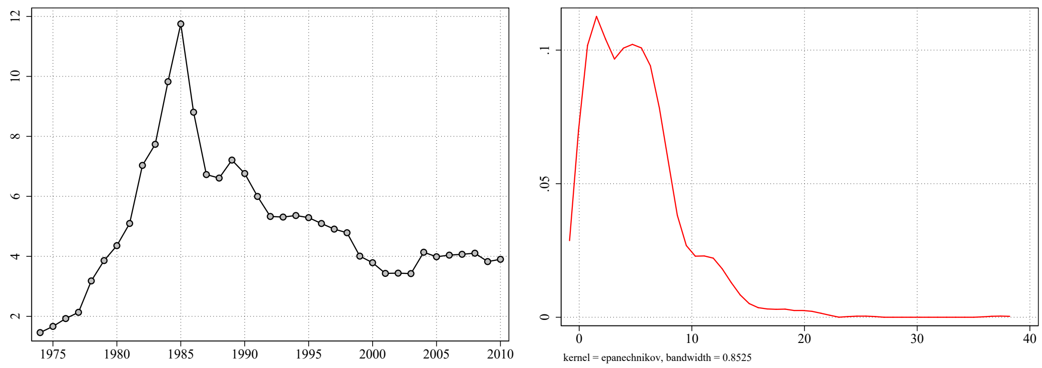
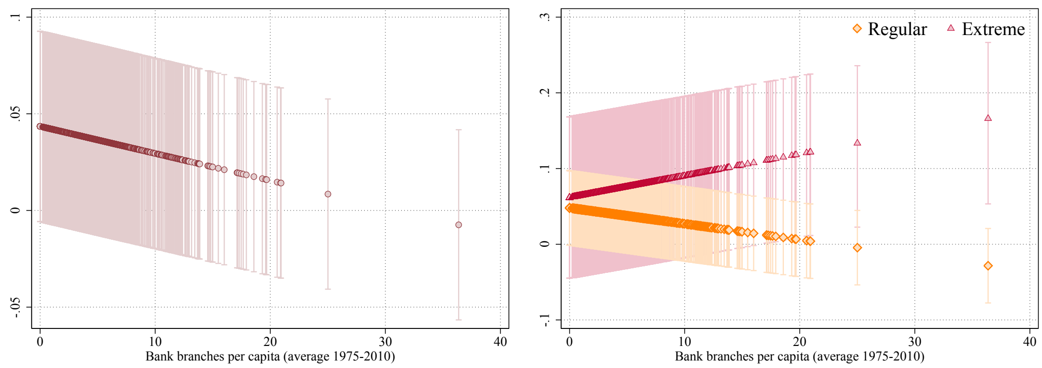
Figure 6.4: **Bank branches *per capita* in semiarid Brazil**



(a) Municipalities' average

(b) Density: 1975-2010

Figure 6.5: **Drought effect on migration, by the average number of bank branches *per capita* in semiarid Brazil**



(c) *Drought* shock

(d) *Extreme* and *Regular* shock

Note: Figure 6.4 presents estimates of bank branches *per capita* for all 920 municipalities in semiarid Brazil: (a) displays each year average between municipalities and (b) densities of each municipality average for pooled years. In figure 6.5, each dot represent a municipality: (c) uses coefficients of column (1) and (d) of column (5) in Table 6.2 and multiply them by the average 1975-2010 of bank branches *per capita*. Sources are Brazilian Central Bank and Census.

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Table 6.2: **Drought shocks impact on migration**

Semiarid-Brazil municipalities (1975-91; 1996-2010)

Dependent variable: ln(**Migration Rate**)				
	(1)	(2)	(3)	(4)
	$t=-1$	$t=-2$	$t=-1$	$t=-2$
A.				
Drought(t)	0.0435**	0.0235		
	(0.0219)	(0.0213)		
Drought(t)*BB(t)	-0.0014	0.0039		
	(0.0032)	(0.0026)		
B.				
Aridity Index(t)			0.0063	-0.0002
			(0.0087)	(0.0072)
Aridity(t)*BB(t)			0.0007	0.0014*
			(0.0010)	(0.0008)
Bank Branches(t)	-0.0006	0.0017	-0.0032	0.0002
	(0.0027)	(0.0028)	(0.0036)	(0.0035)
Control (Temp)	X	X	X	X
Municipality FE	X	X	X	X
Year FE	X	X	X	X
Observations	28,520	28,520	28,520	28,520
Adjusted R^2	0.313	0.313	0.313	0.313
	(5)	(6)		
	$t=-1$	$t=-2$		
C.				
Extreme(t)	0.0617	0.0047		
	(0.0484)	(0.0513)		
Regular(t)	0.0480**	0.0278		
	(0.0219)	(0.0214)		
Extreme(t)*BB(t)	0.0027	0.0101*		
	(0.0060)	(0.0053)		
Regular(t)*BB(t)	-0.0021	0.0031		
	(0.0032)	(0.0026)		
Bank Branches(t)	-0.0006	0.0016		
	(0.0027)	(0.0029)		
Control (Temp)	X	X		
Municipality FE	X	X		
Year FE	X	X		
Observations	28,520	28,520		
Adjusted R^2	0.313	0.313		

Note: Robust standard error clustered at municipality level in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Migration rate equals migrants per 100,000 inhabitants of each semiarid-Brazil municipality. BB = Number of bank branches in each municipality. Drought events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. AI is the Aridity Index (see text). Sources are Census, Brazilian Central Bank and INMET.

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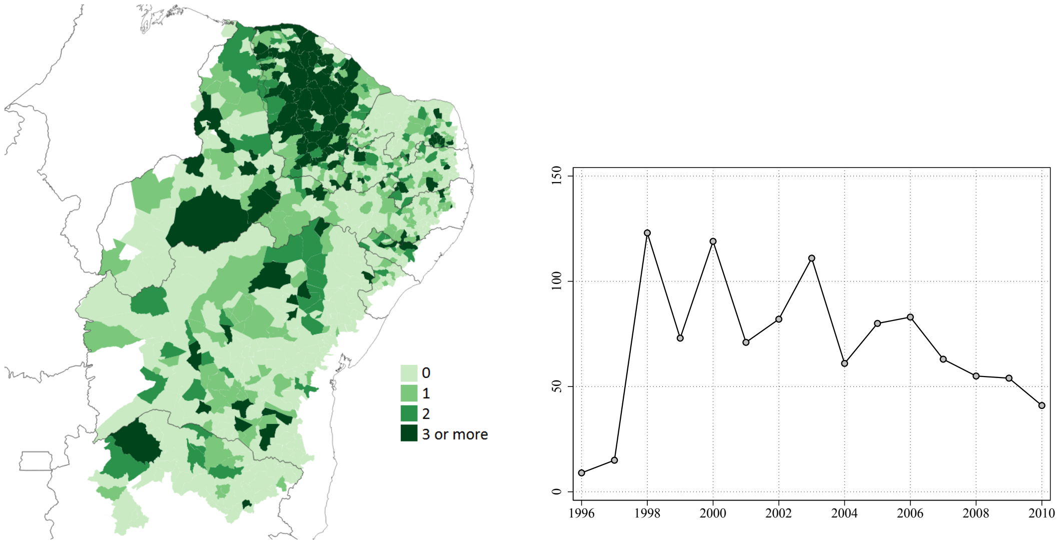
Figure 6.6: **Infrastructure's finished projects**

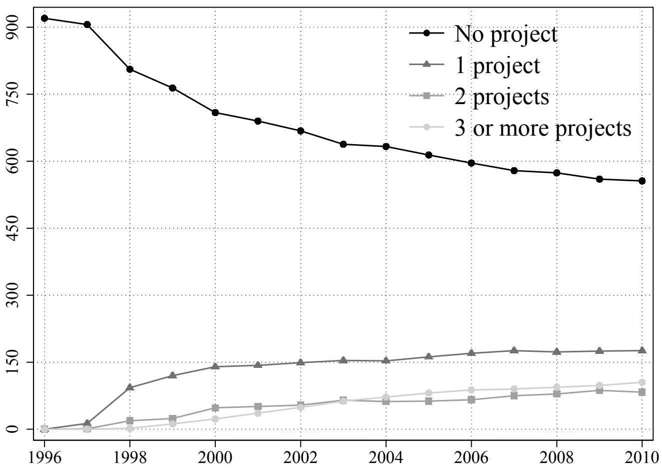
Projects related to a drought mitigation policy, semiarid-Brazil municipalities



(a) Total from 1996-2010 by municipality (b) Total projects by year

Figure 6.7: **Infrastructure dummies variables**

Number of semiarid-Brazil municipalities in each category; projects related to a drought mitigation policy



(c)

Note: Figure 6.6 presents the number of infrastructure's projects related to a drought mitigation policy (e.g. dams) finished in semiarid Brazil. Item (a) displays the total projects from 1996-2010 by municipality and item (b) the evolution by year. Figure 6.7 presents the number of municipalities in semiarid Brazil, from the total of 920, in each infrastructure indicator variable. Each dummy represents the total number of projects finished since the initial year of 1996. Source is *Convênios* from CGU.

Table 6.3: **Drought shocks impact on agricultural output**

Semiarid-Brazil municipalities (1996-2010)

Dependent variable: ln(**Real Agricultural Output**)			
	(1)		(2)
A.		*B.*	
Drought	-0.1081***	Aridity Index	-0.0720***
	(0.0213)		(0.0077)
Drought(-1)	-0.0772***	Aridity Index(-1)	-0.0415***
	(0.0207)		(0.0062)
Drought(-1)*[Infra = 1](-1)	0.1079***	**Aridity(-1)*[Infra = 1](-1)**	0.0176*
	(0.0398)		(0.0098)
Drought(-1)*[Infra = 2](-1)	0.2243***	**Aridity(-1)*[Infra = 2](-1)**	0.0570**
	(0.0676)		(0.0234)
Drought(-1)*[Infra = ≥ 3](-1)	0.0738	**Aridity(-1)*[Infra = ≥ 3](-1)**	0.0151
	(0.0623)		(0.0160)
Control (Temp)	X	Control (Temp)	X
Municipality FE	X	Municipality FE	X
Year FE	X	Year FE	X
Observations	12,880	Observations	12,880
Adjusted R^2	0.754	Adjusted R^2	0.760
	(3)		
C.			
Extreme	-0.4123***		
	(0.0396)		
Regular	-0.1327***		
	(0.0212)		
Extreme(-1)	-0.2347***		
	(0.0388)		
Regular(-1)	-0.0735***		
	(0.0209)		
Extreme(-1)*[Infra = 1](-1)	0.2330***		
	(0.0723)		
Extreme(-1)*[Infra = 2](-1)	0.3187**		
	(0.1236)		
Extreme(-1)*[Infra ≥ 3](-1)	0.2262**		
	(0.0971)		
Regular(-1)*[Infra = 1](-1)	0.0763*		
	(0.0406)		
Regular(-1)*[Infra = 2](-1)	0.1852***		
	(0.0683)		
Regular(-1)*[Infra ≥ 3](-1)	0.0392		
	(0.0628)		
Control (Temp)	X		
Municipality FE	X		
Year FE	X		
Observations	12,880		
Adjusted R^2	0.758		

Note: Robust standard error clustered at municipality level in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Agricultural production is on real *per capita* terms of 2000's Brazilian Real prices. Infra = Infrastructure's finished projects that are related to a drought mitigation policy (e.g. water dams). Drought events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. AI is the Aridity Index (see text). Sources are Census, *Convênios* from CGU and INMET.

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Table 6.4: **Drought shocks impact on migration**

Semiarid-Brazil municipalities (1996-2010)

	Dependent variable: ln(**Migration Rate**)			
	(1)	(2)	(3)	(4)
	$t = -1$	$t = -2$	$t = -1$	$t = -2$
A.				
Drought(t)	-0.0012	-0.0118		
	(0.0270)	(0.0296)		
Drought(t)*[Infra = 1](t)	-0.0483	0.0075		
	(0.0544)	(0.0502)		
Drought(t)*[Infra = 2](t)	-0.1216*	-0.0192		
	(0.0667)	(0.0728)		
Drought(t)*[Infra ≥ 3](t)	0.0044	0.0534		
	(0.0507)	(0.0557)		
B.				
Aridity Index(t)			0.0222**	0.0064
			(0.0089)	(0.0099)
Aridity(t)*[Infra = 1](t)			-0.0395**	0.0014
			(0.0190)	(0.0146)
Aridity(t)*[Infra = 2](t)			-0.0349	-0.0441
			(0.0228)	(0.0477)
Aridity(t)*[Infra ≥ 3](t)			-0.0152	0.0108
			(0.0142)	(0.0193)
Control (Temp)	X	X	X	X
Municipality FE	X	X	X	X
Year FE	X	X	X	X
Observations	12,880	11,960	12,880	11,960
Adjusted R^2	0.298	0.302	0.298	0.302
	(5)	(6)		
	$t = -1$	$t = -2$		
C.				
Extreme(t)	0.1039**	-0.0065		
	(0.0469)	(0.0577)		
Regular(t)	0.0030	-0.0112		
	(0.0268)	(0.0294)		
Extreme(t)*[Infra = 1](t)	-0.2208*	0.0696		
	(0.1241)	(0.1161)		
Extreme(t)*[Infra = 2](t)	-0.0797	-0.3945		
	(0.1656)	(0.3382)		
Extreme(t)*[Infra ≥ 3](t)	-0.0921	0.1401		
	(0.0767)	(0.1303)		
Regular(t)*[Infra = 1](t)	-0.0293	0.0002		
	(0.0548)	(0.0503)		
Regular(t)*[Infra = 2](t)	-0.1249*	0.0102		
	(0.0693)	(0.0681)		
Regular(t)*[Infra ≥ 3](t)	0.0109	0.0433		
	(0.0516)	(0.0543)		
Control (Temp)	X	X		
Municipality FE	X	X		
Year FE	X	X		
Observations	12,880	11,960		
Adjusted R^2	0.298	0.302		

Note: Robust standard error clustered at municipality level in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Migration rate equals migrants per 100,000 inhabitants of each semiarid-Brazil municipality. Infra = Infrastructure's finished projects that are related to a drought mitigation policy (e.g. water dams). Drought events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. *AI* is the Aridity Index (see text). Sources are Census, *Convênios* from CGU and INMET.

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7 Conclusion

In this article, we analyze the out-migration response in semiarid-Brazil after drought shocks. Migration can be an attractive choice after negative productivity shocks, especially in more vulnerable areas where credit and liquidity are limited. Ongoing climate change discussion fears a future mobility crisis, yet there are ambiguous results in the literature, motivating the present study. Bearing in mind, for example, that moving costs resources, the sign of the migration response after negative shocks is not entirely clear.

We applied the widely used two-way fixed effect (FE) approach. Although results presented here should be taken with care, they provide evidence that in Brazil semiarid case, agricultural output suffers and migration reacts positively to weather-driven economic shocks. Municipality migration rate increase by 6-7% following a drought. Dividing the sample, it becomes clear that the out-migration response comes from mostly from the 70s and 80s, and that there is no relevant distinction between whites and non-whites and across genders.

A mechanism analysis points to a scenario where more local liquidity, in the form of the rural social security benefit, decrease the migration response in more extreme drought events. However, municipalities with different magnitudes of bank branches (therefore credit availability) do not seem to migrate more or less. Finally, findings show that after the 90s, projects that mitigate the disruption of water scarcity are effective in alleviating the negative agricultural impact, but do not alter the out-migration reaction due to drought.

So what could explain the decrease in out-migration? Drought still hurts the agriculture in recent years. Since rural social security expanded greatly in 1991, we can deduce that part of the decrease of migration comes from this channel of more liquidity to cope with shocks. Other mechanisms that are out of the scope of this study could influence as well. We conjecture, for example, that conditional cash transfer (CCT) programs such as the Child Labor Eradication Program (PETI) and Bolsa Familia, very relevant in the Northeast, might be another source of liquidity to cope with the drought shocks.

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A
Appendix

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Table A.1: **Migration rate by subgroups**

Mean and standard deviation of semiarid-Brazil municipalities

	1975-80	**1982-91**	**1996-2000**	**2001-10**
I. Color				
Non-white	685.6 (461.5)	546.2 (444.2)	527.5 (337.9)	552.7 (415.4)
White	477.1 (324.7)	334.4 (301.7)	388.6 (273.4)	300.7 (271.4)
P-value of mean difference	0.00***	0.00***	0.00***	0.00***
White share in migration	0.41	0.38	0.42	0.36
White share in population		0.31	0.30	0.35
II. Gender				
Female	578.6 (340)	452.9 (330.2)	478 (276.1)	424.4 (292)
Male	587.4 (369.1)	429.7 (333.8)	444.8 (267.3)	429 (332.6)
P-value of mean difference	0.20	0.00***	0.00***	0.32
Male share in migration	0.50	0.49	0.48	0.50
Male share in population		0.48	0.49	0.50
III.Age				
Young (< 37 years)	923 (532.7)	695.2 (484.2)	738.8 (393.3)	677.2 (455.8)
Old (≥ 37 years)	243 (188.5)	187.4 (208.4)	183.9 (164.2)	176.2 (180.9)
P-value of mean difference	0.00***	0.00***	0.00***	0.00***
Old share in migration	0.20	0.21	0.20	0.21
Old share in population		0.35	0.37	0.36
Observations	5,520	9,200	4,600	9,200

a Share of total population between 18 and 55 years old in semiarid-Brazil municipalities. Source is the previous Census: in the 2^{nd} column 1980, 3^{rd} 1991, 4^{th} 2000.

Note: *** p<0.01, ** p<0.05, * p<0.1. Migration rate equals migrants per 100,000 inhabitants of each semiarid-Brazil municipality. Migrants are between 18 and 55 years old; the third panel (*III. Age*) considers 37 years of age as the threshold for young and old. Non-white in the first panel (*I. Color*) includes black, mixed ("*pardo*") and Asian races. Source is Census.

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Table A.2: **Drought shocks impact on agricultural output**
Semiarid-Brazil municipalities (1975-91; 1996-2010)

Dependent variable: ln(**Real Agricultural Output**)				
	(1) **1975-80**	(2) **1982-91**	(3) **1996-2000**	(4) **2001-10**
A.				
Drought	-0.0716***	-0.0180	-0.1916***	-0.1155***
	(0.0237)	(0.0233)	(0.0349)	(0.0217)
Temperature	-0.0702***	-0.0805***	-0.2105***	0.0188
	(0.0163)	(0.0109)	(0.0313)	(0.0209)
Munic FE	X	X	X	X
Year FE	X	X	X	X
Observations	5,520	9,200	4,600	9,200
Adjusted R^2	0.691	0.622	0.740	0.800
	(5)	(6)	(7)	(8)
B.				
Aridity Index	-0.1307***	-0.0608***	-0.0793***	-0.1143***
	(0.0114)	(0.0070)	(0.0091)	(0.0127)
Temperature	-0.0245	-0.0385***	-0.1334***	0.0721***
	(0.0155)	(0.0117)	(0.0308)	(0.0212)
Munic FE	X	X	X	X
Year FE	X	X	X	X
Observations	5,520	9,200	4,600	9,200
Adjusted R^2	0.695	0.624	0.740	0.803
	(9)	(10)	(11)	(12)
C.				
Extreme	-0.5709***	-0.3173***	-0.6575***	-0.3898***
	(0.0547)	(0.0425)	(0.0656)	(0.0434)
Regular	-0.0909***	-0.0191	-0.2421***	-0.1314***
	(0.0239)	(0.0229)	(0.0345)	(0.0214)
Temperature	-0.0459***	-0.0495***	-0.1344***	0.0394*
	(0.0151)	(0.0114)	(0.0304)	(0.0203)
Munic FE	X	X	X	X
Year FE	X	X	X	X
Observations	5,520	9,200	4,600	9,200
Adjusted R^2	0.691	0.622	0.740	0.800

Note: Robust standard error clustered at municipality level in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Agricultural production is on real *per capita* terms of 2000's Brazilian Real prices. Drought events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. *AI* is the Aridity Index (see text). Sources are Census, IBGE and INMET.

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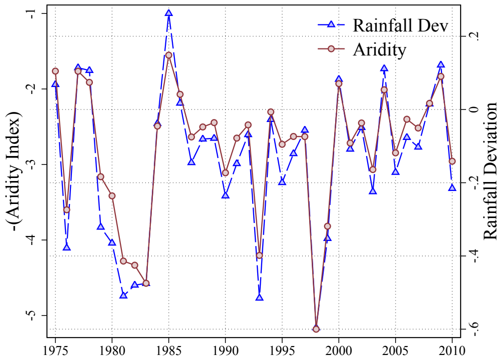
Figure A.1: **Average of rainfall deviation and Aridity Index**

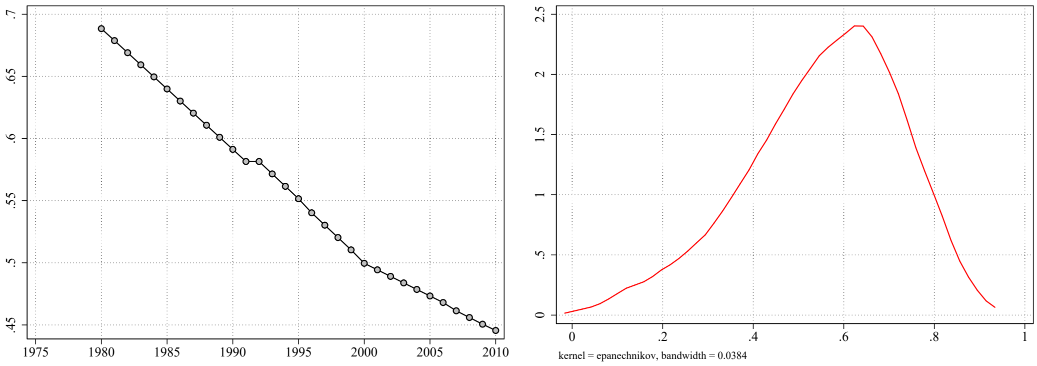
Semiarid-Brazil municipalities



Note: Graphs show the average across semiarid-Brazil municipalities of the Aridity Index and rainfall deviation measure. Rainfall deviation is replicated as Rocha and Soares (2015). Source is INMET.

Figure A.2: **Rural area proportion**

Semiarid-Brazil municipalities



(a) Municipalities' average (b) Density

Note: Figure presents estimates of the rural area proportion for all 920 municipalities in semiarid Brazil. Item (a) displays each year average between municipalities and item (b) displays densities of each municipality average for pooled years 1980-2010. Source is Census.

Table A.3: **Recipient population share for rural social security**

Semiarid-Brazil municipalities, 2000 and 2010

Dependent variable: **Recipient Share**	
Eligible Share	1.173***
	(0.0170)
Rural Area Proportion	-0.0249***
	(0.00237)
Observations	1,839
Adjusted R^2	0.891

Note: Robust standard errors in parenthesis; *** $p<0.01$, ** $p<0.05$, * $p<0.1$.

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Table A.4: **Infrastructure's finished projects from 1996 to 2010**
Projects related to a drought mitigation policy, semiarid-Brazil

State	DNOCS	Other agencies	Total
Piauí	22	74	96
Ceará	278	234	512
Rio Grande do Norte	7	83	90
Paraíba	4	108	112
Pernambuco	2	77	79
Alagoas	3	28	31
Sergipe	7	0	7
Bahia	6	108	114
Minas Gerais	7	17	24
Total	336	729	**1065**

Note: Infrastructure's finished projects that are related to a drought mitigation policy (e.g. water dams). Source is *Convênios* from CGU.

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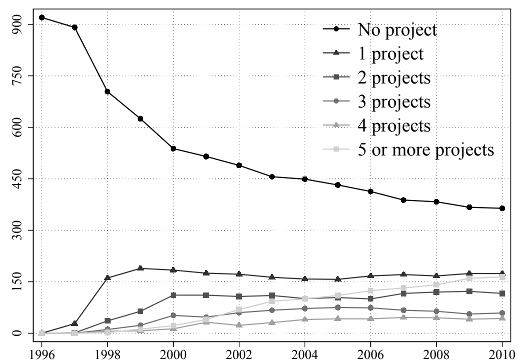
Figure A.3: **Infrastructure dummies variables**
Number of semiarid-Brazil municipalities in each category; projects related to a drought mitigation policy



(d) With municipality spillover $\leq$ 20 km

Note: Figure 6.7, item (d), presents the number of municipalities in semiarid Brazil, from the total of 920, in each infrastructure indicator variable. Each dummy represents the total number of projects finished since the initial year of 1996. Municipality spillover considers that infrastructure also benefit the neighbor and is defined when municipalities' centroids are less than 20 kilometers apart. Source is *Convênios* from CGU.

Table A.5: **Drought shocks impact on agricultural output**

Semiarid-Brazil municipalities (1996-2010), with municipality spillover = 20km

Dependent variable: ln(**Real Agricultural Output**)			
	(1)		(2)
A.		*B.*	
Drought	-0.1120***	Aridity Index	-0.0712***
	(0.0215)		(0.0077)
Drought(-1)	-0.1032***	Aridity Index(-1)	-0.0420***
	(0.0237)		(0.0070)
Drought(-1)*[Infra = 1](-1)	0.0625	**Aridity(-1)*[Infra = 1](-1)**	0.0001
	(0.0437)		(0.0099)
Drought(-1)*[Infra = 2](-1)	0.1993***	**Aridity(-1)*[Infra = 2](-1)**	0.0384**
	(0.0533)		(0.0167)
Drought(-1)*[Infra = 3](-1)	0.1651**	**Aridity(-1)*[Infra = 3](-1)**	0.0392*
	(0.0836)		(0.0205)
Drought(-1)*[Infra = 4](-1)	0.2346***	**Aridity(-1)*[Infra = 4](-1)**	0.0850***
	(0.0717)		(0.0263)
Drought(-1)*[Infra = $\geq$ 5](-1)	0.1546***	**Aridity(-1)*[Infra = $\geq$ 5](-1)**	0.0314
	(0.0561)		(0.0197)
Control (Temp)	X	Control (Temp)	X
Municipality FE	X	Municipality FE	X
Year FE	X	Year FE	X
Observations	12,880	Observations	12,880
Adjusted R^2	0.755	Adjusted R^2	0.760
	(3)		
C.			
Extreme	-0.4089***		
	(0.0396)		
Regular	-0.1356***		
	(0.0213)		
Extreme(-1)	-0.2403***		
	(0.0430)		
Regular(-1)	-0.0927***		
	(0.0242)		
Extreme(-1)*[Infra = 1](-1)	0.0493		
	(0.0728)		
Extreme(-1)*[Infra = 2](-1)	0.2328**		
	(0.1122)		
Extreme(-1)*[Infra = 3](-1)	0.2671**		
	(0.1087)		
Extreme(-1)*[Infra = 4](-1)	0.3519**		
	(0.1371)		
Extreme(-1)*[Infra $\geq$ 5](-1)	0.2457***		
	(0.0948)		
Regular(-1)*[Infra = 1](-1)	0.0400		
	(0.0438)		
Regular(-1)*[Infra = 2](-1)	0.1629***		
	(0.0529)		
Regular(-1)*[Infra = 3](-1)	0.1117		
	(0.0838)		
Regular(-1)*[Infra = 4](-1)	0.1879***		
	(0.0713)		
Regular(-1)*[Infra $\geq$ 5](-1)	0.1059*		
	(0.0563)		
Control (Temp)	X		
Municipality FE	X		
Year FE	X		
Observations	12,880		
Adjusted R^2	0.758		

Note: Robust standard error clustered at municipality level in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Agricultural production is on real *per capita* terms of 2000's Brazilian Real prices. Infra = Infrastructure's finished projects that are related to a drought mitigation policy (e.g. water dams). Municipality spillover considers that infrastructure also benefit the neighbor and is defined when municipalities' centroids are less than 20 kilometers apart. Drought events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. AI is the Aridity Index (see text). Sources are Census, *Convênios* from CGU and INMET.

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Table A.6: **Drought shocks impact on migration**

Semiarid-Brazil municipalities (1996-2010), with municipality spillover = 20km

	Dependent variable: ln(**Migration Rate**)				
	(1)	(2)		(3)	(4)
	$t = -1$	$t = -2$		$t = -1$	$t = -2$
A.			*B.*		
Drought(t)	-0.0002	-0.0107	Aridity Index(t)	0.0215**	0.0033
	(0.0257)	(0.0297)		(0.0093)	(0.0104)
Drought(t)*[Infra = 1](t)	-0.0064	0.0075	**Aridity(t)*[Infra = 1](t)**	-0.0196	0.0109
	(0.0441)	(0.0446)		(0.0124)	(0.0123)
Drought(t)*[Infra = 2](t)	-0.0894	-0.0534	**Aridity(t)*[Infra = 2](t)**	-0.0130	0.0015
	(0.0622)	(0.0649)		(0.0217)	(0.0268)
Drought(t)*[Infra = 3](t)	0.0710	0.0553	**Aridity(t)*[Infra = 3](t)**	-0.0176	-0.0033
	(0.1059)	(0.0928)		(0.0541)	(0.0354)
Drought(t)*[Infra = 4](t)	-0.0970	0.0437	**Aridity(t)*[Infra = 4](t)**	-0.0468	0.0410
	(0.1505)	(0.1556)		(0.0506)	(0.0477)
Drought(t)*[Infra ≥ 5](t)	-0.0689	0.0108	**Aridity(t)*[Infra ≥ 5](t)**	-0.0351	-0.0179
	(0.0695)	(0.0760)		(0.0286)	(0.0363)
Control (Temp)	X	X		X	X
Municipality FE	X	X		X	X
Year FE	X	X		X	X
Observations	12,880	11,960		12,880	11,960
Adjusted R^2	0.298	0.302		0.298	0.302
	(5)	(6)			
	$t = -1$	$t = -2$			
C.					
Extreme(t)	0.0892**	-0.0022			
	(0.0441)	(0.0566)			
Regular(t)	0.0035	-0.0097			
	(0.0257)	(0.0296)			
Extreme(t)*[Infra = 1](t)	-0.0536	0.0533			
	(0.0837)	(0.1007)			
Extreme(t)*[Infra = 2](t)	-0.1683	0.0162			
	(0.1901)	(0.1627)			
Extreme(t)*[Infra = 3](t)	-0.0706	-0.2470			
	(0.4141)	(0.3132)			
Extreme(t)*[Infra = 4](t)	-0.0065	-0.0268			
	(0.1645)	(0.1796)			
Extreme(t)*[Infra ≥ 5](t)	0.0144	-0.1383			
	(0.1162)	(0.1986)			
Regular(t)*[Infra = 1](t)	0.0013	0.0001			
	(0.0450)	(0.0452)			
Regular(t)*[Infra = 2](t)	-0.0791	-0.0604			
	(0.0618)	(0.0647)			
Regular(t)*[Infra = 3](t)	0.0849	0.0791			
	(0.1040)	(0.0896)			
Regular(t)*[Infra = 4](t)	-0.1015	0.0473			
	(0.1530)	(0.1599)			
Regular(t)*[Infra ≥ 5](t)	-0.0698	0.0212			
	(0.0703)	(0.0745)			
Control (Temp)	X	X			
Municipality FE	X	X			
Year FE	X	X			
Observations	12,880	11,960			
Adjusted R^2	0.298	0.302			

Note: Robust standard error clustered at municipality level in parentheses; *** p<0.01, ** p<0.05, * p<0.1. Migration rate equals migrants per 100,000 inhabitants of each semiarid-Brazil municipality. Infra = Infrastructure's finished projects that are related to a drought mitigation policy (e.g. water dams). Municipality spillover considers that infrastructure also benefit the neighbor and is defined when municipalities' centroids are less than 20 kilometers apart. Drought events means $AI \geq 2$. *Extreme* events means $AI \geq 5$, *Regular* means $2 \leq AI < 5$. AI is the Aridity Index (see text). Sources are Census, *Convênios* from CGU and INMET.

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