Natural Disasters and Economic Growth in Northeast Brazil: Evidence from Municipal Economies of the Ceará State

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August 9, 2018

Abstract

Based on an unexplored data set on disasters in Brazil, the current study shows that the direct damage of natural disasters reduces the GDP growth rate of municipal economies in Ceará state, Northeast Brazil. The agriculture and service sectors are the most affected economic sectors, while the industrial sector remains unaffected by environmental shocks. Economic growth is particularly responsive to the occurrence of high-scale natural disasters that lead municipalities to declare a state of emergency or public calamity. Regarding public policies, water supply infrastructure increases the resilience of the output growth of services to droughts, whereas disaster microinsurance helps to mitigate the effects of droughts and floods on the economic growth of agriculture in a Brazilian state where family farming is predominant and highly vulnerable to natural disasters.

Key-words: Economic growth, natural disasters, Ceará, Brazil.

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1. Introduction

Natural disasters have devastating impacts on human and economic development. In only two decades (1992-2012), environmental disasters affected 4.4 billion people worldwide, claimed 1.3 million lives and caused US$ 2 trillion in economic losses (UNISDR, 2012). A variety of economic consequences of environmental shocks have been documented by the literature. For instance, natural disasters may cause population mobility in poor (Gray and Mueller, 2012; Drabo and Mbaye, 2015) and rich countries (Strobl, 2011; duPont IV et al., 2015), affect household income and expenditures (Arouri et al., 2015; Lohmann and Lechtenfeld, 2015), and impact the local labour market of affected countries (Halliday, 2012; Coffman and Noy, 2012). Natural hazards also contribute to the maintenance of armed conflicts (Ghimire and Ferreira, 2015) and trap vulnerable populations in poverty (Carter et al., 2006; Jakobsen, 2012; Rodriguez-Oreggia et al., 2012).

Nonetheless, environmental disasters can have either positive or negative effects on economic growth. Some studies have shown that natural hazards boost economic growth (Albala-Bertrand, 1993; Skidmore and Toya, 2002; Noy and Vu, 2010; Fomby et al, 2011; Cunado and Ferreira, 2014), while others provide evidence of negative effects in the short run (Rasmussen, 2004; Noy, 2009; Strobl 2011; 2012), medium run (McDermott et al., 2014) and long run (Raddatz, 2009; Hsiang and Jina, 2014).[2] In particular, Loayza et al. (2012) show that disasters do affect economic growth, but not always negatively, with effects that differ across types of disasters and economic sectors.

Low-income and developing countries are more likely to experience human and economic losses than are developed countries (Toya and Skidmore, 2007), and the growth performances of such countries are especially responsive to environmental shocks (Noy,

[2] Several hypotheses about the response of economic growth to environmental catastrophes in the long run have been tested (Hsiang and Jina, 2014), such as: i) the "creative destruction" hypothesis (Skidmore and Toya, 2002); the "build back better" hypothesis (Hallegatte et al., 2007; Cuaresma et al., 2008; Hallegatte and Dumas, 2009); the "recovery to trend" hypothesis (Strobl, 2011); and iv) the "no recovery" hypothesis (Anttila-Hughes and Hsiang, 2013).

2009; Strobl, 2012; Loayza et al., 2012).[3] Political instability (Cavallo et al., 2013), an absent/imperfect financial sector (McDermott et al., 2014), low access to international markets and a lack of institutional quality (Felbermayr and Gröschl, 2014) appear to be important mediating factors.

Notably, Latin America is exposed to a variety of natural disasters that can jeopardize economic growth (Stillwell, 1992). For instance, Brazil is highly exposed to climate disasters, and ongoing global warming will further increase the risk of such environmental hazards in the near future. Predictions from the International Panel of Climate Change show the intensification of droughts in Northeast Brazil throughout the 21st century due to increasing global temperatures (IPCC, 2012). Between 1995 and 2014, almost half of the total losses due to climate disasters occurred in this specific region of the country (CEPED, 2016).

The current investigation aims to provide evidence of the impact of natural disasters on the economic growth of municipalities in Ceará state, which is one of the states most affected by climatic hazards in Brazil (CEPED, 2016). Within the great semiarid region lies 87% of the state's territory, as well as 56% of its population.[4] Although its population is the eighth largest among Brazilian states (i.e., 8.5 million, which is slightly larger than the population of Austria), Ceará had the fifth lowest per capita GDP (US$ 6,652 PPP) in 2010, which is economically comparable to Guatemala (US$ 6,578 PPP). Such a level of exposure and economic vulnerability to environmental hazards is shared by the other Northeast states, making Ceará a suitable and representative case study area.

This investigation relies on an unexplored data source on disasters in Brazil. The information on natural disasters comes from the Damage Assessment Report (Relatório de Avaliação de Danos – AVADAN) carried out by the Civil Defence when a disaster occurs.

[3] Developed countries with a large concentration of wealth in hazardous areas are also highly exposed to environmental hazards. However, they are often better equipped financially and institutionally to adopt explicit measures to effectively respond and adapt to natural disasters than are developing countries (IPCC, 2012).

[4] The Brazilian semiarid region is characterized by annual precipitation below 800mm, a dryness index of 0.5 or below, and a risk of drought of at least 60%.

Findings show that economic growth is negatively affected by damage from droughts and floods, which have consequences for the agriculture and service sectors. The output growth of municipalities is particularly responsive to large-scale disasters that lead municipalities to declare a state of emergency or public calamity. Furthermore, water supply infrastructure (WSI) increases the resilience of the service sector to droughts but not the agriculture sector, which is highly dependent on water resources. However, the Garantia-Safra programme (GS) – a microinsurance policy for natural disasters – helps municipalities to mitigate the effects of droughts and floods on the economic growth of the agriculture sector.

Therefore, this paper contributes to the growing literature dedicated to understanding the effects of natural disasters on economic growth (Cavallo and Noy, 2011) by adding new evidence from a large developing country. In particular, the current study shows how responsive economic growth is to environmental shocks in a poor region of Brazil, whereas other recent studies provided evidence from developed regions of the country (Ribeiro et al., 2014; Haddad and Texeira, 2015; Lima and Barbosa, 2018). Moreover, the study provides evidence of the role played by water supply infrastructure (Hallegatte, 2009; Gutiérrez et al, 2014) and disaster microinsurance (Cummins and Mahul, 2009; Clarck and Grenham, 2013) in the adaptation and response to natural disasters associated with climate change.

The remainder of this study is structured as follows: section 2 describes the data sources, section 3 presents the empirical strategy, and section 4 analyses the results. Finally, section 5 concludes the study.

2. Data

2.1 Study area

Ceará state, the study area, is located in Northeast Brazil (see Figure 1) and has a total area of 148,886 km² (or 1.8% of country territory). The climate is predominantly tropical hot semiarid, which favours the occurrence of drought episodes that are often associated with large-scale climate phenomena, such as El Niño and La Niña, or with an intense meridional sea surface temperature (SST) gradient over the tropical Atlantic (Marengo et al., 2017).

[INSERT FIGURE 1 HERE]

The population size of municipalities in the state is nearly 46 thousand inhabitants on average, with Fortaleza (the state capital) being the largest municipality (2.45 million inhabitants) and Guramiranga being the smallest (4.1 thousand inhabitants). Regarding economic activity, the service sector is the most important economic sector for the municipalities and is responsible for almost 64% of total GDP. The share of industry in GDP is 21%, while that of agriculture is only 6%.[5] The metropolitan region of Fortaleza (14 municipalities) has 42% of the total population and approximately 65% of the total GDP (72% and 65% of the respective gross added value of service and industry, and only 9% of the gross added value of agriculture). In contrast, municipalities within the semiarid region are responsible for slightly more than a third of the total GDP (37%), and 81% of the gross added value of agriculture.

2.2 Information on natural disasters in Brazil

This analysis uses information from the AVADAN, which comprises information about natural disasters, human disasters and mixed disasters (i.e., when human actions contribute to natural disasters). It must be filled out by trained professionals of the Civil Defence within the first 120 hours following a disaster (MIN, 2007).[6]

The AVADAN provides information on the affected areas (e.g., urban and rural areas), human damage (e.g., number of homeless, displaced, injured, sick, and fatalities), and

[5] Information on GDP is obtained from the Instituto Brasileiro de Geografia e Estatística (IBGE). The data source of municipal GDP includes total GDP and gross added value from agriculture, services/commerce and industry. It also includes the gross added value from public administration and taxes (with discounted subsides). It can be access at https://sidra.ibge.gov.br/pesquisa/pib-munic/tabelas.

[6] The AVADAN database is available at https://s2id-search.labtrans.ufsc.br/.

direct damage to i) buildings (e.g., homes; health and education establishments; public and community infrastructure; and rural, industrial and commercial buildings), ii) natural resources (e.g., water, land, air, flora and fauna), iii) the economy (e.g., crops, livestock, manufacturing, and services/commerce), and iv) essential services (e.g., the water and power supply, transportation, communication, sewage and garbage collection, health and education service, and food supply). Taking IRDR (2014) as a reference, the AVADAN provides compatible information to compute loss indicators and covers the same categories of hazards as international databases on disasters such as the EM-DAT.

In 2012, Brazil adopted the classification and corresponding codification of the International Disaster Database (EM-DAT) of the Center for Research on the Epidemiology of Disasters (CRED) in order to bring national legislation into line with international criteria. In the same year, the AVADAN was replaced by a shorter and less detailed version of the Damage Assessment Report, called the Information Disaster Form (Formulário de Informação do Desastre). To preserve the homogeneity of the data source, this analysis is restricted to the period 2002-2011.

2.3 Descriptive statistics on natural disasters in Ceará

As shown in Table 1, extreme climate events are the most frequent disaster in Ceará, with droughts (76.4) accounting for three times more reported disasters than floods (22.9%) from 2002 to 2011. Other natural disasters include coastal erosion, landslides, and forest fires, which account for less than 1% of reported events. It is worth noting that 75% of all recorded disasters (76% of droughts and 74% of flood events) in Ceará have Damage Assessment

Reports.[7] The proportions regarding drought and flood events in the EM-DAT are 30% and 49%, respectively, as reported by Loayza et al. (2012).

[INSERT TABLE 1 HERE]

Table 1 also shows that the average annual losses per municipality is approximately R$ 6 million (or US$ 4.3 million PPP) in Ceará, with losses from floods being almost three times larger than losses from droughts. Such a difference is mainly explained by the direct damage to homes, as well as to public and private infrastructure, when floods take place in urban areas. Other disasters, specifically coastal erosion, have average losses of about R$ 110 million (or US$ 79 million PPP), making them potential outliers in the sample. Moreover, approximately 45% of the total sample has information on the direct damage caused by natural disasters, with 34% related to droughts and 12.5% related to floods.

In addition, reported droughts and floods are associated with the precipitation in the municipalities. Figure 2(a) shows that drought episodes are highly predominant over the years, except in 2004 and 2009 when floods were the most reported natural disaster.[8] The pairwise correlation across time between the average annual precipitation and total reports of droughts is -0.719 (p-value<0.05), and regarding total reports of floods, it is 0.774 (p-value<0.05). Across municipalities, the pairwise correlation between total number of reports and average annual precipitation is -0.663 (p-value<0.05).

[INSERT FIGURE 2 HERE]

[7] According to CEPED (2013), the other 25% of disaster records without a damage assessment report (AVADAN) come from preliminary notifications of disasters, technical reports, public ordinances and decrees, and newspapers.

[8] Although average annual precipitation was below 600 mm in 2010, the average level of reservoirs was about 70% at the end of rainfall season (May 30, 2010). The excess of rainfall in 2009 explains the relatively small number of droughts in 2010. For further information, access http://www.hidro.ce.gov.br.

Although the number of notifications is informative about the frequency of disasters, the direct damage of natural disasters is useful for capturing the intensity of the environmental shocks.[9] That is,

$$ND_{i,t} = \sum_j \frac{Cost\ of\ Disaster_{i,j,t}}{Population_{i,t-1}},$$

where i is the index of municipalities, j indicates the type of disaster (i.e., droughts and floods), and t is the year of the disaster. Disaster costs are standardized by lagged population size in order to avoid the contemporaneous effect of environmental hazards on population (Noy, 2009). Because the per capita costs of natural disasters exhibit large standard errors, the natural log is computed in order to prevent the potential influence of outliers (see Table 1).

2.4 Determinants of output growth

Furthermore, determinants of economic growth may reduce the vulnerability of municipalities to environmental hazards (Toya and Skidmore, 2007), making them important confounding factors if they are not taken into account in the analysis.[10] Table 2 provides average and standard deviations of the output growth and control variables.

[INSERT TABLE 2 HERE]

In the neoclassical growth literature, the accumulation of physical and human capital and technological progress are key determinants of economic growth (Durlauf et al., 2005). Because of the absence of an appropriate measure of physical capital, an index based on principal components is obtained using post offices, radio stations, schools and health establishments. The index ranges from 0 to 100, and each covariate is normalized by

[9] Several studies have relied on different measures of natural disasters to study their impacts on economic growth. Noy (2009) used people killed/affected divided by lagged population size, and costs of the disaster divided by lagged GDP. Similarly, Toya and Skidmore (2007) measure losses as the number of deaths and economic damage/GDP. Loazya et al. (2012) used affected population normalized by population size, while Skidmore and Toya (2002) relied on the number of disaster events.

[10] Table A1 in the Online Appendix displays pairwise correlations.

population size. Electricity consumption is included as a proxy for investment in physical capital. Enrolment in high school, normalized by population size, is included as a proxy for human capital stock. Technology is assumed to be exogenous and constant across municipalities (Mankiw et al., 1992).

In addition, per capita public spending is included in order to capture the effect of local government consumption on growth (Barro, 1990). The relevance of the formal labour market to economic growth is captured by the proportion of formal workers relative to population size (La Porta and Shleifer, 2014). Finally, vulnerability to natural disasters is accounted for by the following variables (WHO, 2013): hospital beds per inhabitant and water supply infrastructure (i.e., number of reservoirs and water pipeline systems).

3. Empirical strategy

The empirical strategy relies on the standard empirical growth equation proposed by Islam (1995). Several studies have extended the growth equation to incorporate the intensity of natural disasters, assuming a multiplicative risk formulation (Noy, 2009; Loayza et al., 2012; Felbermayr and Gröschl, 2014). That is,

$$\Delta \ln y_{i,t} = \beta \ln y_{i,t-1} + \rho \ln ND_{i,t} + \theta \ln X_{i,t} + \mu_t + \lambda_i + \varepsilon_{i,t} \quad (1)$$

where $y_{i,t}$ is the output per capita of municipality i in year t, and $y_{i,t-1}$ is the lagged outut per capita. The vector of explanatory variables includes covariates that account for determinants of economic growth in the municipalities, X_{it}, and the measure of the direct damage caused by natural disasters, ND_{it}. The formulation also includes the time-specific effect, μ_t, which reflects the potential productivity growth and common shocks over time. The unit-specific fixed effect, λ_i, captures effects from unobserved fixed characteristics of municipalities that can be correlated with economic growth and costs of natural disasters.

The generalized method of moments (GMM) developed for dynamic models of panel data (Holtz-Eakin et al., 1988; Arellano and Bond 1991; and Arellano and Bover, 1995) is adopted as the empirical strategy, taking advantage of first differences and internal instruments to deal with unobserved heterogeneity and simultaneity issues. However, some explanatory variables may be highly persistent in the short panel, producing weak internal instruments (Durlauf et al., 2005). In this case, the GMM system (Arellano and Bover, 1995; Blundell and Bond, 1998) is used in the current study.[11]

A particular issue is whether damage caused by natural disasters is endogenously determined in equation (1). In the literature, the measures of natural disasters are usually treated as exogenous covariates (Skidmore and Toya, 2002; Raddatz, 2007; Noy, 2009; Loayza et al., 2012), although human and economic losses are likely to depend on the level of development of the affected area (Toya and Skidmore, 2007).[12] Loayza et al. (2012) argue that reverse causation is not an issue in equation (1) because economic growth may only help countries or regions reduce their vulnerability to environmental hazards in the long run.

In the short run, however, several unobserved policy responses to natural disasters may compensate for natural disasters or even improve the economic growth of the affected municipalities.[13] Thus, the direct damage from natural disasters is likely to be endogenously determined in equation (1). Since natural disasters are associated with municipal precipitation in Ceará (see Figure 2), the deviation of the annual precipitation of municipalities relative to

[11] This method not only uses lagged levels as instruments for first differences, but lagged first differences are also used as instruments for levels. This use requires an extra set of moment conditions in order to achieve consistency and efficiency of the estimators (Roodman, 2009).

[12] This specific issue is partially addressed by the presence of lagged per capita GDP, a set of time-varying controls that accounts for differences in the level of municipal development (see Table 2) and unobserved municipal fixed effects.

[13] For instance, drought responses may involve the distribution of seeds and equipment (e.g., a rainfed water cistern) in rural areas, access of family farmers to a disaster microinsurance program, availability of credit in public banks and fund transfers to cope with disaster damage, and improvements in the water supply infrastructure of municipalities (Gutierrez et al., 2014).

their historical average over the last 30 years is used as an external instrument.[14] A robust analysis is provided in order to test whether the output growth of municipalities is responsive to the lack and excess of rainfall.

4. Results

4.1 Baseline estimations

Table 3 provides the estimated effects of the direct damage of natural disasters, measured by per capita costs, on the output growth rate of municipal economies. The results show that disaster damage negatively affects the economic growth of municipalities in Ceará, Brazil. Specifically, the output growth of agriculture is negatively affected by damage from droughts and floods, while the economic growth of services is affected by damage from floods. Industry remains unresponsive to natural disasters.

[INSERT TABLE 3 HERE]

It is worth noting that the estimations in Table 3 account for the infrastructure of municipalities, which implies that the effects do not operate through physical capital formation (Loayza et al., 2012). In agriculture, the effects of droughts are likely to operate through the loss of efficiency caused by the lack of water resources. For instance, droughts can cause crop losses and reduce livestock (Chimeli et al., 2008). Floods, in contrast, can destroy crops that are sensitive to excessive rainfall, such as corn, beans, rice and cassava, which are predominant in Ceará (Sun et al., 2006). In the service sector, floods can lead firms to suffer asset loss, prevent workers from arriving at their workplaces or leaving the job earlier (Haddad and Texeira, 2015). Consequently, floods reduce labour productivity (Leiter et al., 2009).

[14] Validation of the instruments is obtained by using the Hansen test for overidentifying restrictions, in which the null hypothesis is the exact identification of the model.

The results from Table 3 also contrast with studies that have documented a positive effect of floods on the output growth rate of agriculture (Loayza et al., 2012; Cunado and Ferreira, 2014). One hypothesis is that water accumulation from floods might result in relative gains for total factor productivity (e.g., intensive use of irrigation technology), which might outweigh losses from the destruction of public infrastructure and land (Loayza et al., 2012). However, rainfed agriculture is predominant in Ceará, since only 1.5% of the total area of all rural establishments uses irrigation technology. In addition, family farming occupies 44% of the total area of rural establishments in Ceará, making it responsible for 64% of total crops and 51% of livestock (Ceará, 2009).[15] In Brazil, family farming exhibits low access to agricultural policies (e.g., credit policies and technical assistance) and technologies, as well as poor market and socioeconomic integration (Medina et al., 2015), suggesting a high vulnerability to environmental shocks.

In terms of magnitude, an increase of one standard deviation in direct damage from natural disasters reduces the output growth rate by 3.1% (=-0.0129×2.4369). This effect is about one third of the estimated effect of natural disasters on the output growth of developing countries, as documented by Noy (2009). The same variation in the direct damage from droughts leads to a decrease of approximately 2.4% (=-0.0117×2.0830) in the GDP growth rate and nearly 6.5% (=-0.0298×2.0830) in output growth of agriculture. In the case of floods, a similar variation in direct damage implies a drop of approximately 2.3% (=-0.0132×1.7557) in overall output growth and a reduction of 4.2% (=-0.0240×1.7557) and 1% (=-0.0057×1.7557), respectively, in the economic growth rates of agriculture and services.

4.2 Robustness analysis

[15] According to the 2006 Brazilian Agriculture Census (Censo Agropecuário 2006), carried out by the Instituto Brasileiro de Geografia e Estatística. Further information can be accessed on the following website: https://sidra.ibge.gov.br/pesquisa/censo-agropecuario/censo-agropecuario-2006/segunda-apuracao.

It is important to confirm whether the results from Table 3 find support in alternative estimations of equation (1). The current subsection present two robustness checks that aim to verify i) whether the output growth of municipalities is responsive to the lack and excess of rainfall and ii) whether the economic growth of municipalities is affected by low- or high-scale natural disasters.

Response of Output Growth to the Lack and Excess of Rainfall

In this subsection, equation (1) is re-estimated by replacing the direct damage from natural disasters with the following binary variables: i) the lack of rainfall is defined as $I(Deviation < p25\ or - 24.9\%)$; and ii) the excess of rainfall is expressed as $I(Deviation > \ p75\ or\ 21.7\%)$.[16]

[INSERT TABLE 4 HERE]

Table 4 shows that the overall growth rate is responsive to excessive rainfall but not to the lack of rainfall. Municipalities with excessive rainfall experience a 4.6% drop in overall output growth, which is particularly driven by the effects on the agriculture and service sectors.[17] The output growth of agriculture is also responsive to the lack of rainfall, which is the most susceptible economic sector to natural disasters in Ceará. Such evidence supports the baseline results in Table 3.

The non-significance of the estimate for the lack of rainfall, however, does not mean that output growth is unaffected by droughts. Indeed, the economic growth performance of municipalities in Ceará may be responsive to severe droughts. This leads to the following robust analysis that aims to verify whether the output growth of municipalities is responsive to low- and high-scale natural disasters.

[16] The measure is expressed as $Deviation = 100 \times (P_{it} - \bar{P}_i)$, where P_{it} is precipitation in millimeters of municipality i in year t, and $\bar{P}_i$ is the historical mean of precipitation in the previous 30 years relative year t. The average deviation is -0.52% (and median value is -4.4%) with a standard deviation of 34.4.

[17] Felbermayr and Gröschl (2014) find that a drought episode reduces the economic growth rate across the country by 1.3%.

Response of the output growth to large natural disasters

The AVADAN provides information about the scale of disasters (i.e., small, medium, large and very large), taking into consideration not only human and material losses but also the level of local vulnerability and the risks of a worsening disaster scenario. Based on such classification, Civil Defence recommends whether the Federal Government should recognize an emergency situation (i.e., large-scale disaster) or a public calamity condition (i.e., a very large disaster) (MIN, 2007). Thus, equation (1) is re-estimated with the number of low-scale (ND_{it}^{L}) and high-scale disasters (ND_{it}^{H}), that is,

$$\Delta \ln y_{i,t} = \beta \ln y_{i,t-1} + \varphi \ln ND_{it}^{H} + \phi \ln ND_{it}^{L} + \theta \ln X_{i,t} + \mu_t + \lambda_i + \varepsilon_{i,t}. \quad (2)$$

Table 5 shows that output growth is only affected by the number of high-scale natural disasters, particularly by high-scale droughts and floods.

[INSERT TABLE 5 HERE]

Notice that the economic growth rate of the service sector is particularly affected by high-scale floods. Recent evidence from Brazil has shown the negative consequences of intense floods on economic growth in developed states. For instance, Ribeiro et al. (2014) show that the 2008 floods in Santa Catarina reduced industrial production by 5.1%, while Lima and Barbosa (2018) show a drop of approximately 7.6% in GDP per capita. Haddad and Teixeira (2015) find that floods reduce city growth and residents' welfare in São Paulo, although economic activity in large urban centres tends to recover quickly from severe floods (Kocornik-Mina et al., 2015).

Notice that the linear combination of estimated coefficients $\left(\hat{\varphi} + \hat{\phi}\right)$ provides the average effect of the episodes of natural disasters regardless their scale of magnitude. This evidence is aligned with the baseline results in Table 3. The linear combination in column (1) suggests that an increase of one standard deviation in the number of natural disasters leads to a reduction of approximately 1.6% (=-0.0302×0.5457) in the output growth rate.

Additional robustness analyses

Two additional robustness checks are performed in the current study, both of which are available in the Online Appendix. Table A2 shows the absence of persistence in the effects of the direct damage from natural disasters, while Table A3 replicates Table 3 by including variables that capture the party alignment of mayors with state governors and presidents between 2002 and 2011. If a mayor's party alignment facilitates the recognition of a state of emergency or a public calamity, then such an alignment would favour municipalities in accessing fund transfers that help them cope with the disaster damage, undermining estimates in Table 3. Results show that this is not the case in Ceará, since the estimates remain unchanged after accounting for mayors' party alignments.

4.3 Heterogeneous Analsis

The role of water supply infrastructure

In the past two decades, investment in water supply infrastructure has been the main resilience policy for droughts in Ceará (Gutiérrez et al., 2014). Therefore, it is important to test whether the water supply infrastructure of municipalities can attenuate the effects of natural disasters on the output growth rate. Water supply infrastructure is proxied by the sum of total water reservoirs and water pipeline systems (with a mean value and standard deviation equal to 1.34 and 1.58, respectively). To test such a hypothesis, equation (1) is re-estimated to include interactions between direct damage and the measures of WSI, that is,

$$\Delta \ln y_{i,t} = \beta \ln y_{i,t-1} + \rho \ln ND_{i,t} + \phi WSI_{i,t} + \delta\left(\ln ND_{i,t} \times WSI_{i,t}\right) + \theta \ln X_{i,t} + \mu_t + \lambda_i + \varepsilon_{i,t}. \quad (3)$$

Estimated interactions show that WSI helps municipalities to mitigate the effect of natural disasters on the output growth of the service sector but does not mitigate the impact on the agriculture sector. Perhaps this reflects rural-urban differences in the access to water resources in Ceará, since public investments in water reservoirs and pipeline systems aim to guarantee access to water in urban areas rather than rural areas.[18]

A water reservoir or water pipeline system would reduce the magnitude of the impact of the direct damage of droughts on the output of services by almost 30%. Thus, provision of WSI to municipalities increases the resilience of the service sector to direct damage from droughts.

[INSERT TABLE 6 HERE]

The Garantia-Safra programme

The Garantia-Safra programme is a disaster microinsurance policy funded by the federal and state governments, as well as the municipalities.[19] It is one of the actions of the National Programme for Strengthening Family Agriculture (Plano Nacional de Fortalecimento da Agricultura Familiar – PRONAF) and aims to ensure a minimum income (approximately 1.5 times the minimum wage) to family farmers who joined the programme before planting season and who live in municipalities with at least 50% of crop losses due to droughts or floods.[20] The programme covers the Northeast region and part of Minas Gerais and Espírito

[18] According to the 2010 Demographic Census, about 96% of urban domiciles and 48% of rural domiciles have access to piped water from the public water supply system (https://sidra.ibge.gov.br/tabela/3497).
[19] The Garantia-Safra program was created by the Provisional Act N. 11/2001 and converted into the Law N. 10,420/2002.
[20] The target population of Garantia-Safra consists of family farmers who i) have an average monthly household income equal to or smaller than 1.5 times the minimum wage in the last 12 months before program registration; ii) have no irrigated crops; and iii) have a cultivation area between 0.6 and 5 hectares of beans, corn, rice, cassava and cotton. Small farmers must contribute 2% of the premium value at the time of registration. They must be registered in the program at the beginning of the agricultural year or before planting season (i.e., from January to March).

Santo states, especially municipalities within the semiarid region.[21] On average, 190,619 family farmers joined the programme between 2003 and 2011, while 98,200 received benefits.[22] The programme helps family farmers to smooth consumption and can even be used to maintain their livestock.

To test whether the Garantia-Safra programme can mitigate the impact of natural disasters on the output growth of agriculture, equation (1) is reformulated to include the interaction between the measure of natural disasters and the measure of the Garantia-Safra programme. That is,

$$\Delta \ln y_{i,t} = \beta \ln y_{i,t-1} + \rho \ln ND_{i,t} + \phi GS_{i,t} + \delta\left(\ln ND_{i,t} \times GS_{i,t}\right) + \theta \ln X_{i,t} + \mu_t + \lambda_i + \varepsilon_{i,t}. \quad (4)$$

In Table 7, *Specification 1* uses small farmers benefiting from the programme, normalized by lagged population size (with a mean and standard deviation equal to 2.18% and 3.71, respectively), while *Specification 2* uses the total amount of payments to small farmers, normalized by lagged output (with a mean and standard deviation equal to 0.38% and 0.66, respectively).

[INSERT TABLE 7 HERE]

Estimated interactions in both *Specifications* 1 and 2 show that the Garantia-Safra programme alleviates the effects of direct damage from droughts and floods on the output growth of agriculture. For instance, if 2.18% of the population benefits from the Garantia-Safra programme in an affected municipality, then the magnitude of the impact of the direct damage of droughts reduces by almost 18% and by nearly 27% in the case of floods. Thus, the Garantia-Safra programme mitigates the effects of natural disasters on the output growth of agriculture in Ceará.

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[21] Information about the program can be accessed at http://www.mda.gov.br/sitemda/secretaria/saf-garantia/sobre-o-programa.

[22] Data on the Garantia-Safra program comes from the Ministry of Agrarian Development (Ministério do Desenvolvimento Agrário). See Table A4 in the Online Appendix for descriptive statistics about the Garantia-Safra programme in Ceará.

5. Conclusion

Based on an unexplored database on natural disasters in Brazil, the current study shows that damage from environmental shocks reduces the GDP growth rate of municipal economies in Ceará state, Northeast Brazil. The output growth of agriculture is affected by damage caused by droughts and floods, while the output growth of services is only responsive to damage caused by floods. The economic growth of municipalities is especially responsive to the occurrence of high-scale natural disasters that lead to an emergency condition or public calamity. This is worrisome evidence, since global warming has tended to intensify environmental hazards in Northeast Brazil throughout the 21st century (IPCC, 2012) with particular consequences for agricultural productivity in Ceará state (Ferreira Filho and Moraes, 2014; Assunção and Chen, 2016).

Despite improvements in the management of water resources over the last few decades, there are still challenges in responding and adapting to natural disasters, especially droughts in Ceará (Gutiérrez et al., 2014). For instance, water supply infrastructure increases the resilience of the economic growth of the service sector to droughts but not for the agriculture sector. This may reflect urban-rural inequality in the access to water resources in Ceará. Thus, public policy should prioritize water provision to rural areas, incorporating technologies that help small farmers to better adapt to environmental hazards (e.g., water desalination and reuse). In terms of policy response, the Garantia-Safra plays an important role by mitigating the effects of droughts and floods on the economic growth of agriculture in a Brazilian state where family farming is predominant and highly vulnerable to natural disasters.

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FIGURES

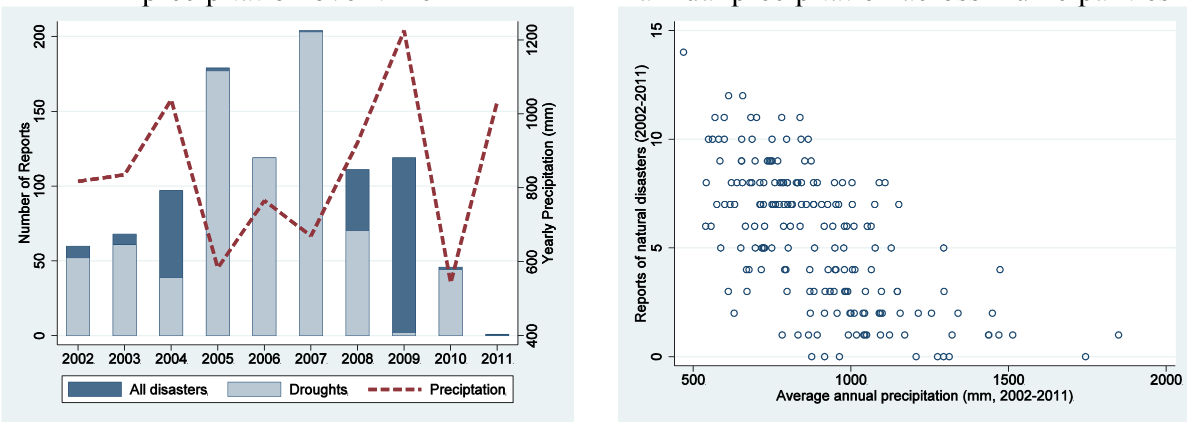
Figure 1. Map of Ceará State, Northeast, Brazil

Source: Author's own elaboration.

Figure 2. Damage assessment reports and annual precipitation in Ceará

(a) Frequency of reports and average annual precipitation over time

(b) Scatter-plot: disaster reports and average annual precipitation across municipalities



Source: AVADAN/Defesa Civil and Fundação Cearense de Meteorologia e Recursos Hídricos - FUNCEME.

TABLES

Table 1. Mean and standard deviation of disaster measures on affected municipalities between 2002 and 2011

	AVADAN/Records*	Losses (R$ Million)	Affected Population (Thousands)	Descriptive Statistics of the Sample		
				Fraction of the Sample with Reports	**Average Number of Reports**	**ln(per capita costs)**
All disasters	1003/1330	6.0169	8.6096	45%	0.5457	1.7592
		(22.8348)	(8.7746)		(0.6735)	(2.4369)
Droughts	766/1009	3.7258	8.8455	34%	0.4168	1.1700
		(12.5049)	(7.6500)		(0.6366)	(2.0830)
Floods	230/311	10.4880	7.8635	12.5%	0.1250	0.6394
		(30.6073)	(11.8469)		(0.3324)	(1.7557)
Other	7/10	109.8326	7.2094	0.4%	0.0038	0.0185
		(131.8186)	(6.5861)		(0.0616)	(0.3195)

Note. Standard deviations are in parentheses. All monetary values are in real terms regarding the GDP deflator of 2012. *Records about natural disasters come from CEPED (2013).

Table 2. Mean and standard deviation of output growth rate and covariates

	Mean/SD
Outcome variables:	
Output growth rate ($\ln GDPpc_t - \ln GDPpc_{t-1}$)	0.0397
	(0.0982)
Agriculture	0.0055
	(0.2832)
Industry	0.0488
	(0.1744)
Service/commerce	0.0460
	(0.0749)
Control variables:	
Natural log of per capita electricity consumption	-1.8346
	(0.8741)
Agriculture	-2.5388
	(0.8778)
Industry	-4.6562
	(2.2418)
Service/commerce	-3.3732
	(0.6935)
Natural log of formal workers per habitant	-6.1568
	(0.8478)
Agriculture	-5.4451
	(4.4482)
Industry	-6.8626
	(2.9636)
Service/commerce	-6.3621
	(0.8193)
Natural log of per capita public spending	6.9408
	(0.3023)
Natural log of high school enrolment per habitant	-3.1412
	(0.2997)
Natural log of hospital beds per habitant	-5.9053
	(2.0072)
Number of reservoirs + (water) pipeline systems	1.3973
	(1.5768)
Infrastructure index (0 – 100)	30.5421
	(18.0534)
Observations	1840

Note. Standard deviations are in parentheses.

Table 3. Effects of direct damage from natural disasters on the output growth of municipalities

	Growth Rate		Economic Sectors (Growth Rate of per capita Added Value)		
	per capita GDP		Agriculture	Industry	Service
	(1)	(2)	(3)	(4)	(5)
All natural disasters	-0.0129***				
	(0.0038)				
Droughts		-0.0117***	-0.0298**	0.0045	-0.0030
		(0.0044)	(0.0118)	(0.0087)	(0.0031)
Floods		-0.0132**	-0.0240**	-0.0070	-0.0057**
		(0.0053)	(0.0116)	(0.0090)	(0.0027)
Lagged per capita GDP	-0.5347***	-0.5456***	-0.8518***	-0.3855***	-0.7876***
	(0.1222)	(0.1156)	(0.0854)	(0.1012)	(0.0868)
Specification tests (p-values)					
Hansen test of overidentification	0.5340	0.5376	0.3220	0.4613	0.5073
Arellano-Bond test for AR(1) in FD	0.0000	0.0000	0.0000	0.0001	0.0235
Arellano-Bond test for AR(2) in FD	0.6414	0.6857	0.6379	0.6888	0.1890
Number of Instruments	67	73	72	73	73
Observations	1,656	1,656	1,656	1,656	1,656

Note. The vector of endogenous variables includes the lagged natural log of per capita GDP, the natural log of per capita electricity consumption, the natural log of formal workers relative to the total population, the natural log of per capita government expenditures, and the natural log of per capita costs of natural disasters. The vector of predetermined variables includes the natural log of enrolments in high school relative to the total population, the infrastructure index (0-100), water supply infrastructure (i.e., number of reservoirs plus water pipeline systems), and the natural log of hospital beds per inhabitants. The deviation of annual precipitation relative to the historical average and its lagged values are used as external instruments. Robust standard errors are in parentheses. All variables are in log terms. ***p-value < 0.01, ** p-value < 0.05, and * p-value < 0.1.

Table 4. Regressing output growth rate during drought and flood episodes

	Growth Rate	Economic Sectors (Growth Rate of per capita Added Value)		
	per capita GDP	Agriculture	Industry	Service
	(1)	(2)	(3)	(4)
Lack of rainfall (= 1 if Deviation < p25)	-0.0213	-0.1266**	-0.0193	0.0015
	(0.0317)	(0.0560)	(0.0507)	(0.0055)
Excess of rainfall (= 1 if Deviation > p75)	-0.0457**	-0.1334***	-0.0408	-0.0177**
	(0.0229)	(0.0429)	(0.0385)	(0.0078)
Lagged per capita GDP	-0.5277***	-0.8428***	-0.3027***	-0.8096***
	(0.1141)	(0.0948)	(0.0597)	(0.0777)
Specification tests (p-values)				
Hansen test of overidentification	0.3847	0.2457	0.5419	0.2276
Arellano-Bond test for AR(1) in FD	0.0001	0.0000	0.0000	0.0219
Arellano-Bond test for AR(2) in FD	0.6937	0.3288	0.7491	0.1619
Number of Instruments	62	62	62	62
Observations	1,656	1,656	1,656	1,656

Note. See the footnote to Table 3 for the list of control variables included in the regressions. Robust standard errors are in parentheses. All variables are in log terms. ***p-value < 0.01, ** p-value < 0.05, and * p-value < 0.1.

Table 5. Effects of episodes of natural disasters on the output growth of municipalities

	Growth Rate per capita GDP		Economic Sectors (Growth Rate of per capita Added Value)		
			Agriculture	Industry	Service
	(1)	(2)	(3)	(4)	(5)
High-scale disasters					
All natural disasters	-0.0215***				
	(0.0079)				
Droughts		-0.0181*	-0.0609***	-0.0132	-0.0073
		(0.0096)	(0.0196)	(0.0135)	(0.0071)
Floods		-0.0320*	-0.0732**	-0.0033	-0.0206**
		(0.0177)	(0.0357)	(0.0220)	(0.0101)
Low-scale disasters					
All natural disasters	-0.0087				
	(0.0053)				
Droughts		-0.0035	-0.0191	-0.0041	-0.0014
		(0.0055)	(0.0129)	(0.0096)	(0.0033)
Floods		-0.0163	-0.0380	0.0120	-0.0064
		(0.0105)	(0.0236)	(0.0165)	(0.0053)
Lagged per capita GDP	-0.5772***	-0.5276***	-0.8772***	-0.3060***	-0.8045***
	(0.1179)	(0.1134)	(0.0948)	(0.0632)	(0.0817)
Linear combination $(\hat{\varphi} + \hat{\phi})$					
All natural disasters	-0.0302***				
	(0.0108)				
Droughts		-0.0216*	-0.0800***	-0.0173	-0.0086
		(0.0121)	(0.0264)	(0.0188)	(0.0088)
Floods		-0.0484**	-0.1112**	0.0087	-0.0270**
		(0.0214)	(0.0462)	(0.0281)	(0.0114)
Specification tests (p-values)					
Hansen test of overidentification	0.4034	0.1619	0.2518	0.5314	0.3770
Arellano-Bond test for AR(1) in FD	0.0000	0.0000	0.0000	0.0000	0.0308
Arellano-Bond test for AR(2) in FD	0.7258	0.5357	0.4566	0.6992	0.1804
Number of Instruments	46	64	64	64	64
Observations	1,656	1,656	1,656	1,656	1,656

Note. See the footnote to Table 3 for the list of control variables included in the regressions. Robust standard errors are in parentheses. All variables are in log terms. ***p-value < 0.01, ** p-value < 0.05, and * p-value < 0.1.

Table 6. Heterogeneous effects of natural disasters on output growth due to water supply infrastructure

	Growth Rate		Economic Sectors (Growth Rate of per capita Added Value)		
	per capita GDP		Agriculture	Industry	Service
	(1)	(2)	(3)	(4)	(5)
Average effect					
All natural disasters	-0.0124**				
	(0.0049)				
Droughts		-0.0110**	-0.0298**	0.0042	-0.0068**
		(0.0046)	(0.0121)	(0.0081)	(0.0033)
Floods		-0.0122**	-0.0273**	-0.0151	-0.0033
		(0.0060)	(0.0136)	(0.0103)	(0.0031)
Interactions with WSI					
All natural disasters x WSI	-0.0001				
	(0.0013)				
Droughts x WSI		0.0001	0.0009	-0.0017	0.0020**
		(0.0013)	(0.0022)	(0.0027)	(0.0009)
Floods x WSI		0.0003	0.0011	0.0021	-0.0004
		(0.0012)	(0.0021)	(0.0019)	(0.0007)
Lagged per capita GDP	-0.5288***	-0.5901***	-0.8528***	-0.3679***	-0.8385***
	(0.1203)	(0.1026)	(0.0870)	(0.0915)	(0.0819)
Specification tests (p-values)					
Hansen test of overidentification	0.4877	0.4083	0.2759	0.3675	0.5121
Arellano-Bond test for AR(1) in FD	0.0000	0.0000	0.0000	0.0000	0.0252
Arellano-Bond test for AR(2) in FD	0.6280	0.7947	0.6376	0.7226	0.2571
Number of Instruments	67	85	84	85	85
Observations	1,656	1,656	1,656	1,656	1,656

Note. See the footnote to Table 3 for the list of control variables included in the regressions. Robust standard errors are in parentheses. All variables are in log terms. ***p-value < 0.01, ** p-value < 0.05, and * p-value < 0.1.

Table 7. Heterogeneous effects of natural disasters on output growth due to the Garantia-Safra programme

	Specification 1 *(Beneficiaries per lagged population)*	Specification 2 *(Total amount of payments per lagged output)*
Average Effect		
Drought	-0.0398***	-0.0419***
	(0.0138)	(0.0149)
Flood	-0.0230**	-0.0264**
	(0.0111)	(0.0123)
Interaction with GS		
Drought x GS	0.0032**	0.0205**
	(0.0015)	(0.0089)
Flood x GS	0.0029**	0.0215**
	(0.0013)	(0.0088)
GS	-0.0189***	-0.1148***
	(0.0055)	(0.0347)
Lagged per capita GDP	-0.7586***	-0.7782***
	(0.0946)	(0.0921)
Specification tests (p-values)	0.3549	0.3736
Hansen test of overidentification	0.0000	0.0000
Arellano-Bond test for AR(1) in FD	0.6537	0.6106
Arellano-Bond test for AR(2) in FD	91	91
Observations	1656	1656

Note. See the footnote to Table 3 for the list of control variables included in the regressions. All variables are in log terms. ***p-value < 0.01, ** p-value < 0.05, and * p-value < 0.1.